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Effects of Prohibiting Harvest of Largemouth Bass on the Largemouth Bass and Bluegill Fisheries in Two Minnesota Lakes[1]

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Abstract.--Effects of an experimental regulation prohibiting harvest of largemouth bass were evaluated for two lakes in the Minneapolis - St. Paul metropolitan area over a 10-year period. The objective of the regulation was to improve the size structure of bluegill populations by limiting recruitment, via increasing abundance of predatory largemouth bass. The evaluation utilized a before-after/control-impact (BACI) experimental design with two experimental regulation lakes and two control lakes. Statistical power of the analyses was low because of the small sample of lakes and high variability of the data, limiting the conclusiveness of the study. There were statistically significant positive effects of the regulation on largemouth bass density in both experimental lakes, and some indication of an improvement in largemouth bass quality. However, there was only a weak negative correlation between largemouth bass density and bluegill recruitment, and as a result the regulation was ineffective at improving the quality of the bluegill fisheries. In addition, growth curves suggested the lack of bluegill ≥ 200 mm may have been the result of selective harvest of large bluegill rather than stunted growth due to excessive bluegill recruitment.

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Introduction

Panfish (primarily sunfish *Lepomis* spp. and crappie *Pomoxis* spp.) were typically the most sought-after species by anglers in summer creel surveys of 28 Minneapolis - St. Paul metropolitan area lakes (Shodeen and Tureson 1975; Tureson 1978a; Tureson 1978b; Gilbertson 1979) and 12 Rice and Le Sueur County, Minnesota lakes (Belford 1989; Pittman 1989). However, many Minnesota anglers express dissatisfaction with the small panfish they typically catch. The problem occurs statewide, and is particularly prevalent in the metropolitan area where high fishing pressure exists. A common idea is that some disturbance, perhaps depletion of predators, has allowed bluegill recruitment to increase and resulted in density dependent slow growth or "stunting." Efforts to alleviate the perceived problem of stunted growth by panfish removal, macrophyte removal, predator stocking, and selective treatment with fish toxicants have had poor or inconsistent results (Scidmore 1960; Davis 1979; Cross et al. 1992; Radomski et al. 1995).

High densities of small, slow-growing bluegill *Lepomis macrochirus* have been described as merely symptoms of another problem -- too few predators, usually largemouth bass *Micropterus salmoides* (Ming 1974; Ming and McDannold 1975). Anderson (1974) suggested that largemouth bass overharvest may be the most serious problem limiting the sustained quality of fishing in most public waters that have satisfactory largemouth bass habitat. Several authors have reported overharvest of largemouth bass leading to bluegill overpopulation and poorer fishing (Graham 1974; Hickman and Congdon 1974; Rasmussen and Michaelson 1974; Ming and McDannold 1975; Anderson 1976; Novinger and Legler 1978).

Restrictions on largemouth bass harvest are frequently contemplated for reducing bluegill recruitment and promoting faster growth. Reduced bag limits, unless extremely restrictive, have little potential for reducing harvest (Hackney 1974; Redmond 1974). Minimum length limits on largemouth bass have improved bluegill population structure in several Midwestern ponds and reservoirs (Anderson 1974; Hickman and Congdon 1974; Rasmussen and Michaelson 1974; Ming and McDannold 1975; Novinger and Legler 1978). However, they frequently have resulted in accumulation of largemouth bass below the size limit, and resulting reductions in growth rates (Farabee 1974; Hickman and Congdon 1974; Rasmussen and Michaelson 1974; Ming and McDannold 1975). Slot length limits may alleviate that problem by allowing harvest of small largemouth bass and protecting fish at sizes where they are still reasonably abundant, fast growing, and effective predators (Anderson 1976). Reduced growth rates of largemouth bass, however, may not be a major concern if improvement in panfish size structure is the primary objective.

Few evaluations of largemouth bass harvest restrictions have been conducted in northern lakes. Two studies in the upper Midwest suggested that bluegill fishing might be improved by restrictive regulations on largemouth bass harvest (Lundquist 1990; Otis 1990). Following implementation of regulations restricting largemouth bass harvest on four Wisconsin lakes, Lundquist (1990) noted increases in relative weight and mean length of angler harvested bluegill, but expected changes in electrofishing catch per unit effort, mean length of sampled bluegill, and growth rates did not occur. For another Wisconsin Lake, Otis (1990) reported increases in the proportion of bluegill ≥ 150 mm following implementation of a regulation protecting predators (primarily largemouth bass). The changes were achieved partially through increased numbers of ≥ 150 mm fish in the population, and partially through decreased numbers of 80-150 mm fish.

Size-selective exploitation by anglers has recently been recognized as another possible important contributor to poor bluegill size structure (Coble 1988; Beard et al. 1997; Drake et al. 1997; Ehlinger 1997; Jennings et al. 1997; Beard and Essington 2000). Jacobson (in review) examined effects of a bluegill bag limit reduction in four Minnesota lakes.

His results indicated that reduction in bluegill harvest may result in improved size structure.

This study was not designed to directly address potential effects of bluegill harvest on size structure. Instead, the objective was to determine if a regulation prohibiting all harvest of largemouth bass could improve the quality of the bluegill fisheries in two Minneapolis - St. Paul metropolitan area lakes by influencing the predator-prey relationship between largemouth bass and bluegill. We hypothesized the regulation, if effective, should: 1) increase density of largemouth bass ≥ 200 mm in experimental lakes relative to control lakes; 2) decrease overall abundance of bluegill in experimental lakes relative to control lakes, as measured by trap net catch; 3) decrease recruitment of bluegill in experimental lakes relative to control lakes, as measured by trap net catch; 4) increase lengths at age of bluegill in experimental lakes relative to control lakes; 5) increase the proportion of bluegill ≥ 150 mm and ≥ 200 mm in experimental lakes relative to control lakes; and 6) increase the mean sizes of angler harvested bluegill in experimental lakes relative to control lakes.

Study Lakes

Four lakes in the Minneapolis - St. Paul metropolitan area were chosen for the study on the basis of similarities in size, classification, morphology, fish species assemblages, and close proximity to one another. Lake areas and maximum depths are as follows: Lake Ann: 47 ha, 14 m; Lake Bavaria: 66 ha, 20 m; Lake Pierson: 125 ha, 12 m; Lake Zumbra: 72 ha, 18 m. The lakes, all in Carver County, are in Lake Class 24 of the Minnesota Department of Natural Resources lake classification system (Schupp 1992). Lakes Ann and Zumbra have not been stocked in the last 25 years. Lake Bavaria was stocked with northern pike *Esox lucius* annually from 1976-1985, except for 1983. Lake Pierson was stocked with northern pike in 1978 and northern pike-muskellunge hybrids (*E. masquinongy*) every two to four years beginning in 1984. Eurasian watermilfoil *Myriophyllum spicatum* became abundant in all lakes by the end of the study. Its presence was first detected in the following years: Lakes Bavaria and Zumbra, 1989; Lake Pierson, 1991; and Lake Ann, 1995.

Based on the results of the first two years of a three-year preliminary sampling phase, Lakes Ann and Bavaria were selected for the experimental regulation, while Lakes Pierson and Zumbra would serve as control lakes with standard regulations. Standard Minnesota largemouth bass regulations are a bag and possession limit of six, no size limit, and a closed season from mid-February through mid-May. The experimental regulation requiring the immediate release of all largemouth bass caught in Lakes Ann and Bavaria was implemented in May 1995 at the opening of the largemouth bass angling season.

Methods

Largemouth bass were sampled by daytime electrofishing in April and May 1992-2001. Each lake was sampled on several dates annually, before the largemouth bass spawning and angling seasons. On each date, the entire shoreline was sampled, then, as time allowed, additional effort was concentrated in areas that appeared to contain high densities of largemouth bass in order to maximize the number of fish captured. All largemouth bass were measured to the nearest millimeter total length (TL), and scale samples were collected for age-growth analysis. The left pelvic fin was removed from each largemouth bass captured in 1992. From 1993 through 2001, an individually numbered t-bar anchor tag was attached to each largemouth bass ≥ 200 mm. Secondary marks of various fin punches were also administered each year.

Spring abundance of largemouth bass ≥ 200 mm TL in each lake was estimated by the Chapman modification of the Schnabel method, and confidence intervals were derived by treating recaptures as Poisson variables (Ricker 1975). Numbers of recaptures of marked largemouth bass were not always large enough to allow unbiased population estimates for individual length classes. Therefore, size structure of the population was estimated from the length frequency of the electrofishing catch. Proportional stock densities (PSD) and relative stock densities (RSD) were calculated following size classifications listed by Gabelhouse (1984), as follows.

PSD = (number of fish ≥ 300 mm TL)/ (number of fish ≥ 200 mm TL) •100;

RSD-P = (number of fish ≥ 380 mm TL)/ (number of fish ≥ 200 mm TL) •100; and

RSD-M = (number of fish ≥ 510 mm TL)/ (number of fish ≥ 200 mm TL) •100

Initial estimates of PSD and RSD were then adjusted for size selectivity of the electrofishing samples. The mean proportion of captured fish (C) that were recaptured (R) was calculated for fish ≥ 200 mm, ≥ 300 mm, and ≥ 380 mm within lakes over all years (Appendix 1). Too few fish ≥ 510 mm TL were recaptured to allow calculating R/C specifically for memorable-size fish. Initial estimates of PSD were multiplied by the R/C ratio for fish ≥ 200 mm, then divided by the R/C ratio for fish ≥ 300 mm; and initial estimates of RSD were multiplied by the R/C ratio for fish ≥ 200 mm, then divided by the R/C ratio for fish ≥ 380 mm. This procedure is equivalent to that described by Lagler (1968).

Bluegill were sampled with trap nets in July 1992-2001. Trap nets also captured other centrarchid species, but catches were judged too low for meaningful analysis. The nets had single 91 cm by 183 cm frames, 13 mm bar-measure mesh, and 10.7 m leads, differing from standard Minnesota lake survey trap nets (Minnesota Department of Natural Resources 1993). Six nets were set overnight for approximately 24 h at index sites on each lake. Use of index sites rather than randomized sampling locations provided more power to detect change over time within lakes, but made comparison of mean values among lakes less meaningful. Nets were set perpendicular to shore, with leads extending to the shoreline. All captured fish were measured to the nearest mm TL. Scale samples were collected from up to 10 fish per 10 mm length class. Proportional stock densities and RSD of bluegill were calculated from length frequencies of all captured fish following size classifications listed by Gabelhouse (1984), as follows.

PSD = (number of fish ≥ 150 mm TL)/ (number of fish ≥ 80 mm TL) •100

RSD-P = (number of fish ≥ 200 mm TL)/ (number of fish ≥ 80 mm TL) •100.

Largemouth bass and bluegill were aged using the scale method (Jearld 1983). Up to 5 randomly selected fish of each species per 10 mm length class per lake were aged from acetate scale impressions. Back-calculations of lengths at age were done by the Fraser-Lee method using standard intercepts of 20 mm for each species (Carlander 1982). Von Bertalanffy growth parameters were calculated using FISHPARM Version 3.0 (Prager et al. 1989). Age frequencies of total catches of bluegill were estimated using age-length keys derived from the aged subsamples (Ricker 1975). Indices of bluegill year class strengths were modeled from trap net catch-at-age data for ages 1-3 (Appendix 2) using the methods of Parsons and Pereira (2001), except we used catch instead of CPUE because effort was constant. Ages 1-3 were used to calculate the indices because they exhibited significant ($P \leq 0.05$) year class effects, and were generally not yet recruited to the angler harvest.

Randomized roving creel surveys were conducted on each lake during the open-water period in 1992-1996 and 2000-2001. Creel surveys began shortly after ice-out in mid-late April and ended in early-mid November, except that October-November data were not collected in 2001 due to a strike by state employees. Surveys were conducted by a single clerk working 8 h days, 5 days a week. All weekend days were sampled, and weekdays were randomly sampled. State holidays (Memorial Day, Independence Day, and Labor Day) were not sampled. One clerk sampled two lakes during either a randomly selected early (dawn to mid-day) or late (mid-day to dusk) shift each workday, and spent approximately 3.5 h on each lake. Four equally-spaced activity counts were made at each lake. Between activity counts, the clerk interviewed fishing parties and recorded responses to survey questions regarding angler attitudes and species sought, the number of fishing lines, trip lengths, numbers of each species harvested or released, and, whenever possible, total lengths of harvested fish. Incomplete fishing trip interviews were updated to complete trip interviews whenever possible. The 1992-1993 data were analyzed following statistical methods of Powell and Bowden (1980), and calculations were made using the Creel Analysis Reporting Program. All other data were analyzed using the Division's GenCreel Angler Survey Analysis Program. The 1992-1996 surveys were stratified by weekday/weekend-holiday, and by month. The 2000-2001 surveys were stratified by weekday/weekend-holiday, and by early/late season (April-June/July-November).

The 2001 angling effort, catch rate, and harvest estimates were adjusted to account for the fact that the creel survey did not include October and November as it did in all other years. Creel data analyses were run for both April-November 2000 and April-September 2000, and correction factors were estimated for 2001 based on the 2000 results. Angler effort, catch rate, and harvest estimates for April-November 2000 were divided by the corresponding values for April-September 2000 to yield correction factors. Correction factors ranged from 0.8505 to 1.1317. Correction factors were always ≥ 1 for effort and harvest estimates, but in many cases correction factors were < 1 for catch rates because catch rates were lower in October and November than earlier in the season. Each 2001 estimate, and its standard error for April-September, were multiplied by the same correction factor calculated from the 2000 results. This procedure assumed coefficients of variation were the same for April-November as for April-September, and probably underesti-mated the true standard errors. However, since all correction factors were near 1.0, it is unlikely the underestimates were large enough to substantially distort the results.

Hypothesis testing for effects of the experimental regulations was accomplished using univariate repeated measures ANOVA in Systat® 8.0 with annual sample values (e.g. population density, trap net catch, PSD, or angler harvest) as dependent variables; period (before or after implementation of experimental regulations) and year as trial factors; and treatment (standard regulations or experimental regulations) as a grouping factor (Wilkinson 1998). Definitions of "before" and "after" varied depending on the data available for a given variable, but in all cases were chosen to maximize the number of years in the analysis while maintaining separation between pre-regulation and post-regulation sample years or year classes, and including equal numbers of years before and after. The *P*-value of the interaction between period and treatment was the relevant term for evaluating the experimental regulations. In other words, did values change significantly differently for the experimental regulation lakes than for the control lakes after the experimental regulations were implemented? Calculated *P*-values ≤ 0.05 were considered significant.

Results

Abundance of largemouth bass and bluegill

Spring population estimates of large-mouth bass ≥ 200 mm TL ranged from 458 in Lake Ann in 1995 to 4,275 in Lake Pierson in 1996 (Table 1). The 1993 Lake Bavaria esti-mate was negatively biased because only two fish were recaptured (Ricker 1975; Appendix 1). Estimated population densities ranged from 7.8/ha in Lake Pierson in 2001, to 37.1/ha in Lake Zumbra in 1994 (Table 1). Estimated densities often fluctuated greatly from year to year within lakes both before and after the experimental regulations were im-plemented (Figure 1). The mean density in the pooled experimental lakes increased 17% from 14.8/ha in the four sampling years before the regulation change (1992-1995) to 17.3/ha in the last four years of the study (1998-2001), while the mean density in the pooled control lakes declined 48% from 24.5/ha to 12.7/ha. However, the overall period X treatment inter-action was not significant (Table 2). Analyses of individual experimental lakes revealed there were significant treatment effects that were obscured by pooling the two lakes. The mean density in Lake Ann decreased 20% from 17.1/ha before the regulation to 13.6/ha after the regulation, but the decline was significantly less than that in pooled control lakes (Figure 2; Table 3), indicating a positive effect of the experimental regulation despite the fact that density declined. The mean density in Lake Bavaria increased 68% from 12.5/ha before to 21.0/ha after, while that in pooled control lakes decreased, indicating a strong positive effect of the experimental regulation (Figure 3; Table 3).

Bluegill was the predominant species in the July trap net catches (Table 4). Catches ranged from 89 in Lake Zumbra in 1992, to 571 in Lake Bavaria in 1999. Within lakes, catches often fluctuated substantially from year to year (Figure 4). The mean catch in the pooled experimental lakes increased from 265 in the three sampling years before the experimental regulations (1992-1994) to 394 in the last three years of the study (1999-2001), while the mean catch in the pooled control lakes declined from 256 to 237. The mean in Lake Ann increased from 312 before to 366 after, and the mean in Lake Bavaria increased from 217 before to 421 after. The overall period X treatment interaction was not significant (Table 2).

Bluegill Recruitment

Indices of bluegill year class strengths were highly variable within and between lakes (Figure 5). Weak 1992 and 1993 bluegill year classes were common statewide, probably due to unusually cool growing seasons (Tomcko and Pierce 1997). There was a significant (P = 0.088) negative correlation between largemouth bass density in year t and bluegill year class index (t year class; t = 1992-2000) for all lakes combined, but the relationship explained only 8.4% of the variability in bluegill year class indices (Figure 6). The mean bluegill year class index in the pooled experimental lakes increased from 2.8 for the 1989-1994 year classes (before experimental regulations) to 4.1 for the 1995-2000 year classes (after experimental regulations), while the mean bluegill year class index in the pooled control lakes increased from 1.9 to 2.9. The increasing trends in all lakes were strongly influenced by the weak 1992 and 1993 year classes, and the overall period X treatment interaction was not significant.

Age and Growth of Largemouth Bass and Bluegill

Mean back-calculated lengths at last annuli of largemouth bass typically reached quality size (≥ 300 mm) at annulus 4 or 5, preferred size (≥ 380 mm) at annulus 6 or 7, and memorable size (≥ 510 mm) at annulus 11 or older (Table 6). Comparisons of mean lengths before and after the regulation changes were limited to annuli 3-5 because

Table 1. Spring population estimates (N) with 95% confidence intervals (C. I.), and spring population densities (N/ha) with 95% confidence intervals, of largemouth bass ≥ 200 mm TL from four study lakes in Carver County, Minnesota. Population estimates were calculated using Chapman's modification of the Schnabel method (Ricker 1975).

	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
L. Ann										
N	667	1318	768	458	615	535	462	733	673	691
(95% C. I.)	(347-1405)	(623-3041)	(424-1535)	(280-789)	(436-900)	(345-868)	(283-796)	(529-1046)	(509-910)	(441-1141)
N/ha	14.2	28.0	16.3	9.7	13.1	11.4	9.8	15.6	14.3	14.7
(95% C. I.)	(7.4-29.9)	(13.2-64.7)	(9.0-32.7)	(6.0-16.8)	(9.3-19.1)	(7.3-18.5)	(6.0-16.9)	(11.2-22.3)	(10.8-19.4)	(9.4-24.3)
L. Bavaria										
N	1226	762	672	643	867	1294	829	1840	1647	1230
(95% C. I.)	(677-2452)	(279-1905)	(416-1143)	(425-1023)	(621-1255)	(733-2496)	(547-1318)	(1289-2722)	(1284-2110)	(866-1808)
N/ha	18.6	11.5	10.2	9.7	13.1	19.6	12.6	27.9	25.0	18.6
(95% C. I.)	(10.3-37.2)	(4.2-28.9)	(6.3-17.3)	(6.4-15.5)	(9.4-19.0)	(11.1-37.8)	(8.3-20.0)	(19.5-41.2)	(19.5-32.0)	(13.1-27.4)
L. Pierson										
N	3749	1445	2713	2762	4275	2522	1127	1658	1121	975
(95% C. I.)	(2071-7498)	(717-3161)	(1603-4898)	(1713-4702)	(2424-8251)	(1490-4553)	(699-1918)	(1196-2369)	(812-1595)	(679-1452)
N/ha	30.0	11.6	21.7	22.1	34.2	20.2	9.0	13.3	9.0	7.8
(95% C. I.)	(16.6-60.0)	(5.7-25.3)	(12.8-39.2)	(13.7-37.6)	(19.4-66.0)	(11.9-36.4)	(5.6-15.3)	(9.6-18.9)	(6.5-12.8)	(5.4-11.6)
L. Zumbra										
N	1150	2527	2670	1614	1041	947	973	895	1217	1417
(95% C. I.)	(691-2037)	(1313-5321)	(1890-3904)	(1142-2359)	(769-1441)	(587-1611)	(575-1756)	(696-1225)	(915-1657)	(968-2160)
N/ha	16.0	35.1	37.1	22.4	14.5	13.1	13.5	12.4	16.9	19.7
(95% C. I.)	(9.6-28.3)	(18.2-73.9)	(26.2-54.2)	(15.9-32.8)	(10.7-20.0)	(8.2-22.4)	(8.0-24.4)	(9.7-17.0)	(12.7-23.0)	(13.4-30.0)

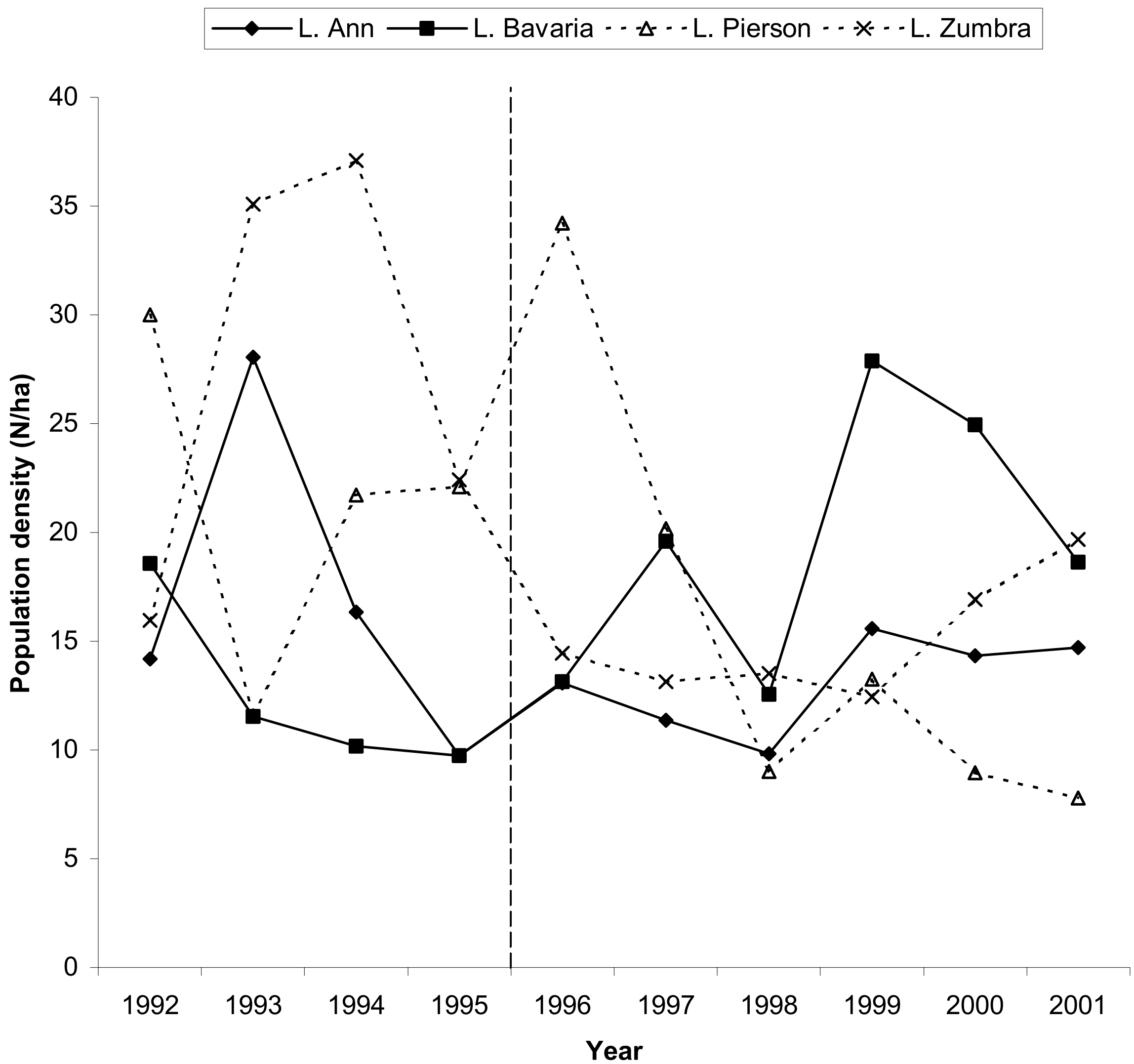

Figure 1. Population density of largemouth bass ≥ 200 mm TL in four lakes in Carver County, Minnesota. Experimental regulation lakes are represented by solid lines, control lakes by dotted lines. The vertical line indicates implementation of the experimental regulation in May 1995 after the 1995 population sample was collected.

Table 2. Results of univariate repeated measures ANOVA of various response variables in two experimental regulation lakes and two control lakes before and after implementation of an experimental regulation prohibiting harvest of largemouth bass. In all cases df = 1, so MS = SS. A *P* value ≤ 0.05 for the period effect indicates an overall difference before and after in all lakes. A *P* value ≤ 0.05 for the period X treatment interaction indicates an effect (positive or negative) of the experimental regulation.

	Period			Period X treatment		
Response variable	SS	F	*P*	SS	F	*P*
Largemouth bass density	171.588	2.390	0.262	411.128	5.726	0.139
Largemouth bass mean length at annulus 3	8437.005	6.257	0.129	1100.978	0.817	0.462
Largemouth bass mean length at annulus 4	5935.873	2.134	0.281	1226.654	0.441	0.575
Largemouth bass mean length at annulus 5	324.811	0.124	0.758	361.475	0.138	0.746
Largemouth bass PSD	1584.845	14.265	0.063	80.011	0.720	0.485
Largemouth bass RSD-P	1630.205	18.206	0.051	392.000	4.378	0.171
Largemouth bass RSD-M	26.281	4.365	0.172	1.201	0.200	0.699
Percentage of angling parties seeking largemouth bass	169.986	4.300	0.174	15.197	0.384	0.598
Angler catch rate of largemouth bass (number/angler·h)	0.061	26.844	**0.035**	0.001	0.559	0.533
Bluegill trap net catch	17985.375	0.456	0.569	33078.375	0.838	0.457
Bluegill recruitment index	15.057	11.062	0.080	0.120	0.088	0.794
Bluegill mean length at annulus 3	2072.042	62.710	**0.016**	1162.042	35.169	**0.027**
Bluegill mean length at annulus 4	2400.000	59.875	**0.016**	541.500	13.509	0.067
Bluegill mean length at annulus 5	1314.062	48.557	**0.020**	33.063	1.222	0.384
Bluegill PSD	124.670	0.149	0.737	3255.010	3.878	0.188
Percentage of angling parties seeking panfish	113.136	0.302	0.638	21.665	0.058	0.832
Angler catch rate of sunfish (number/angler·h)	0.032	0.016	0.911	0.740	0.362	0.608
Sunfish harvest rate (number/angler·h)	0.003	0.010	0.929	0.032	0.116	0.766
Sunfish harvest (number/ha)	352.973	0.133	0.751	131.695	0.049	0.845
Mean length of harvested bluegill	0.375	0.005	0.949	40.042	0.551	0.535
Maximum length of harvested bluegill	204.167	12.437	0.072	6.000	0.365	0.607
Total angling effort	600.000	0.444	0.574	384.000	0.284	0.647

Table 3. Results of univariate repeated measures ANOVA of population densities of largemouth bass ≥ 200 mm comparing individual experimental regulation lakes and two pooled control lakes before (1992-1995) and after (1998-2001) implementation of an experimental regulation prohibiting harvest of largemouth bass.

Source	SS	df	MS	F	*P*
L. Ann and pooled control lakes					
Period	310.083	1	310.083	1531.276	0.016
Period X treatment	92.963	1	92.963	459.078	**0.030**
Error	0.203	1	0.203		
L. Bavaria and pooled control lakes					
Period	14.301	1	14.301	70.621	0.075
Period X treatment	550.807	1	550.807	2720.037	**0.012**
Error	0.203	1	0.203		

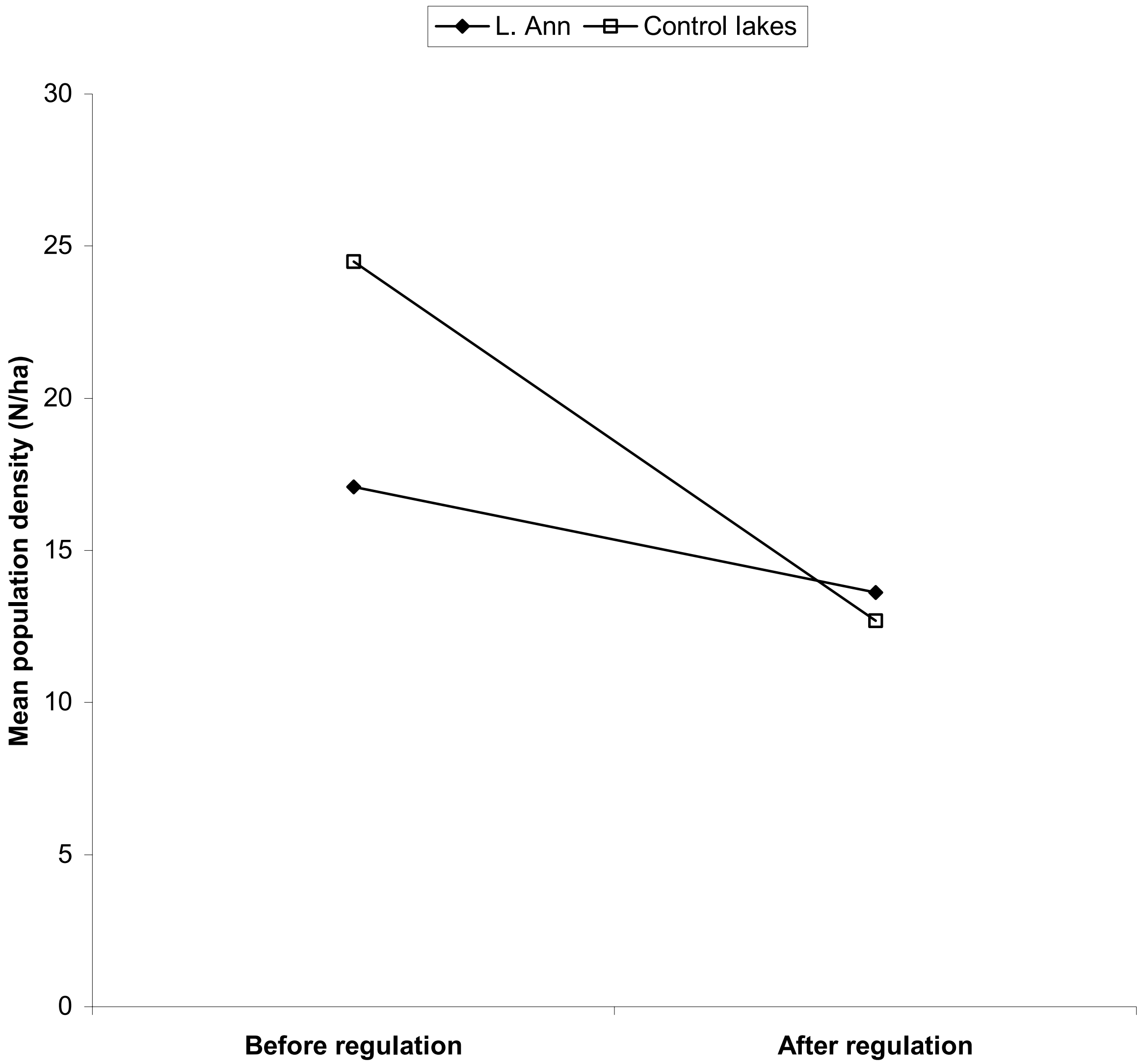

Figure 2. Mean population density of largemouth bass ≥ 200 mm TL in Lake Ann and two pooled control lakes before (1992-1995) and after (1998-2001) implementation of an experimental regulation prohibiting harvest of largemouth bass in Lake Ann.

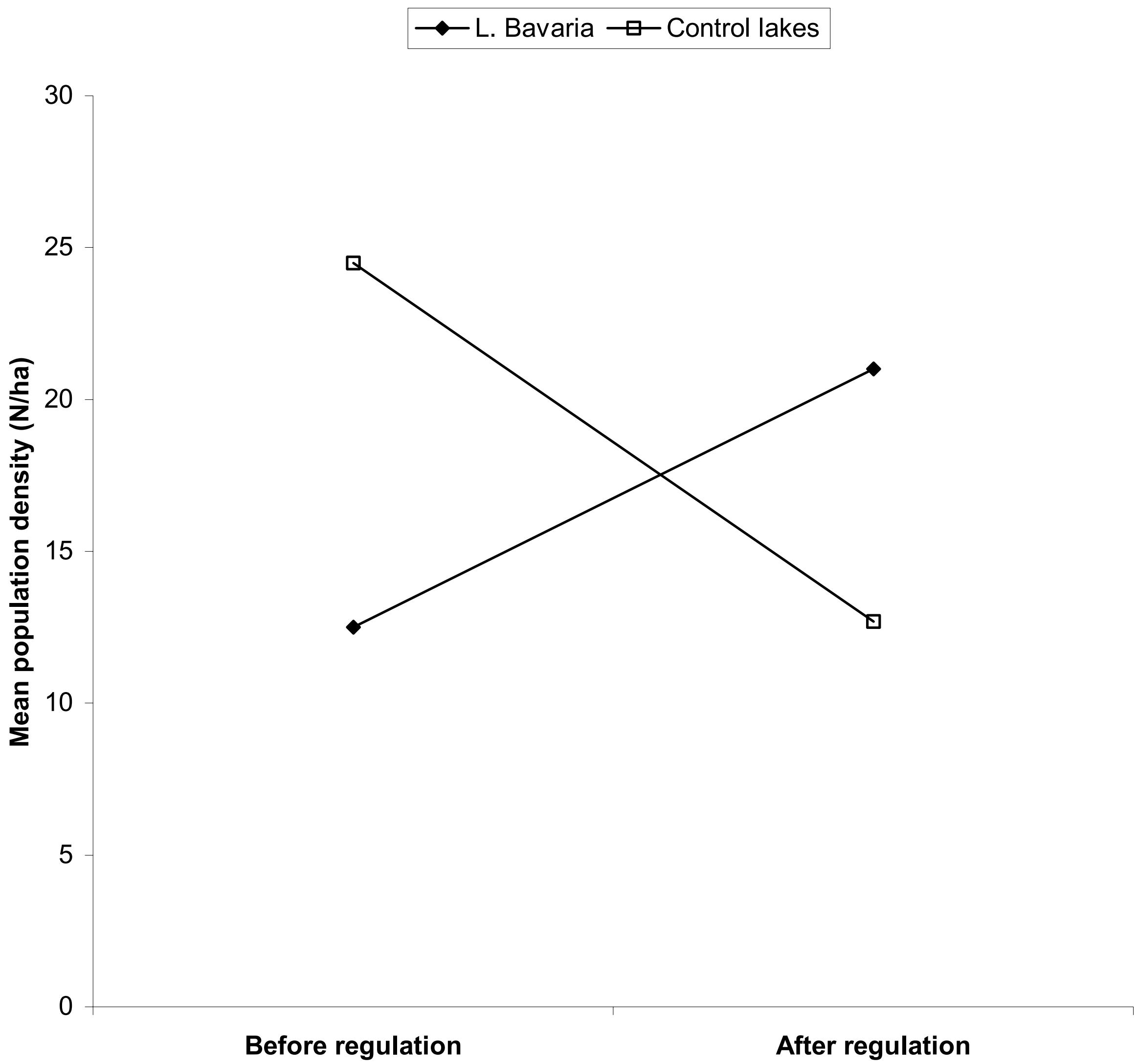

Figure 3. Mean population density of largemouth bass ≥ 200 mm TL in Lake Bavaria and two pooled control lakes before (1992-1995) and after (1998-2001) implementation of an experimental regulation prohibiting harvest of largemouth bass in Lake Bavaria.

Table 4. July trap net catches from four lakes in Carver County, Minnesota. Six trap nets (not the standard Minnesota lake survey type) were set for approximately 24 h at the same index sites each year. Scientific names of species are listed in Table 5.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Ann					
Northern pike										2
Common carp		3								
Golden shiner	3	5		3	15		13	6		2
Emerald shiner			1							
Black bullhead	29	62	8	25	4	16	6	10	3	
Yellow bullhead	7	12		1	2	2	2	10	3	6
Noturus sp.									1	
Green sunfish				1				3	24	19
Pumpkinseed	15	17	21	48	37	24	59	23	22	36
Bluegill	317	433	185	143	128	176	377	502	254	341
Hybrid sunfish	15	26	3	12	11	4	23	18	10	45
Largemouth bass			7	1	36		8	4	7	20
Black crappie	9	5	1	21	7	10	25	11	5	10
Yellow perch	3				8		21	13	8	8
					L. Bavaria					
Northern pike			1			2	1	1	2	1
Common carp	1	1		1	1	2	2	1	1	1
Golden shiner				4						
White sucker			1	1						
Black bullhead		1				11	1			1
Yellow bullhead	11	8	10		6	3	3	19	18	6
Green sunfish								2		1
Pumpkinseed	7	10	16	45	21	4	33	33	5	11
Bluegill	314	142	196	390	335	531	209	571	440	253
Hybrid sunfish	1	2		4	5		4	4	2	1
Largemouth bass	15	1	6	20	4		3	10	7	6
Black crappie	59	19	42	4	9	21	9	7	18	36
Yellow perch			3	14	3		1		1	1
					L. Pierson					
Bowfin	4	4		3		2	1	2	6	
Tiger muskellunge				1						
Northern pike					2			3	3	
Common carp	1	68		4		22	3	4	7	1
Golden shiner							2	2	2	1
Emerald shiner						3	4			
Spotfin shiner								1	1	19
Black bullhead	5	6	4	5		7	2	1		2
Yellow bullhead	33	57	20	9	7	7	4	10	10	4
Brown bullhead										2
Pumpkinseed	4	8	1	8	1	6	1	1	1	1
Bluegill	254	463	279	447	361	460	147	144	138	224
Hybrid sunfish		3	1	1	7	1	1	7	7	3
Largemouth bass		1	31	1	1	3	8	11	11	2
Black crappie	1	6	6	5	6	23	26	73	19	43
Yellow perch			1				3			1

Table 4. Continued.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Zumbra					
Bowfin		1	3	1	2	1	3	4		2
Northern pike							1			
Common carp	2			1						1
Golden shiner	2						1		1	
Emerald shiner						2				
White sucker	7		3							
Black bullhead	11	3	7	5	7	15	6	5	4	43
Yellow bullhead	49	27	18	18	16	9	6	9	12	5
Brown bullhead			1							
Green sunfish								12		2
Pumpkinseed	3	10	6	13	21	10	13	12	5	11
Bluegill	89	289	163	427	430	231	175	310	303	301
Hybrid sunfish		6	3	3	2		1	27	10	18
Largemouth bass			74	4	1	8	4	7	1	1
Black crappie	3	6	18	31	28	132	2	10	5	8
Yellow perch	1		1					1		

Table 5. Scientific names of fishes listed in Table 4.

Common name	Scientific name
Bowfin	*Amia calva*
Northern pike	*Esox lucius*
Tiger muskellunge	*Esox lucius* X *E. masquinongy*
Common carp	*Cyprinus carpio*
Spotfin shiner	*Cyprinella spiloptera*
Golden shiner	*Notemigonus crysoleucas*
Emerald shiner	*Notropis atherinoides*
White sucker	*Catostomus commersoni*
Black bullhead	*Ameiurus melas*
Yellow bullhead	*Ameiurus natalis*
Brown bullhead	*Ameiurus nebulosus*
Green sunfish	*Lepomis cyanellus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Hybrid sunfish	*Lepomis* sp. X *Lepomis* sp.
Largemouth bass	*Micropterus salmoides*
Black crappie	*Pomoxis nigromaculatus*
Yellow perch	*Perca flavescens*

growth histories of older age classes were a combination of pre- and post-regulation growth. Mean length at annulus 3 in pooled experimental lakes increased from 212 mm before the regulation change (1989-1992 year classes) to 233 mm after the regulation change (1995-1998 year classes), while mean length in pooled control lakes increased from 214 mm before to 258 mm after. The mean in Lake Ann increased from 227 mm before to 272 mm after, but the mean in Lake Bavaria decreased from 198 mm before to 194 mm after. Mean length at annulus 4 in pooled experimental lakes increased from 263 mm before the regulation change (1988-1990 year classes) to 280 mm after the regulation change (1995-1997 year classes), while mean length in pooled control lakes increased from 261 mm before to 306 mm after. The mean in Lake Ann increased from 270 mm before to 325 mm after, but the mean in Lake Bavaria decreased from 255 mm before to 235 mm after. Mean length at annulus 5 in pooled experimental lakes remained constant at 334 mm before (1987-1988 year classes)

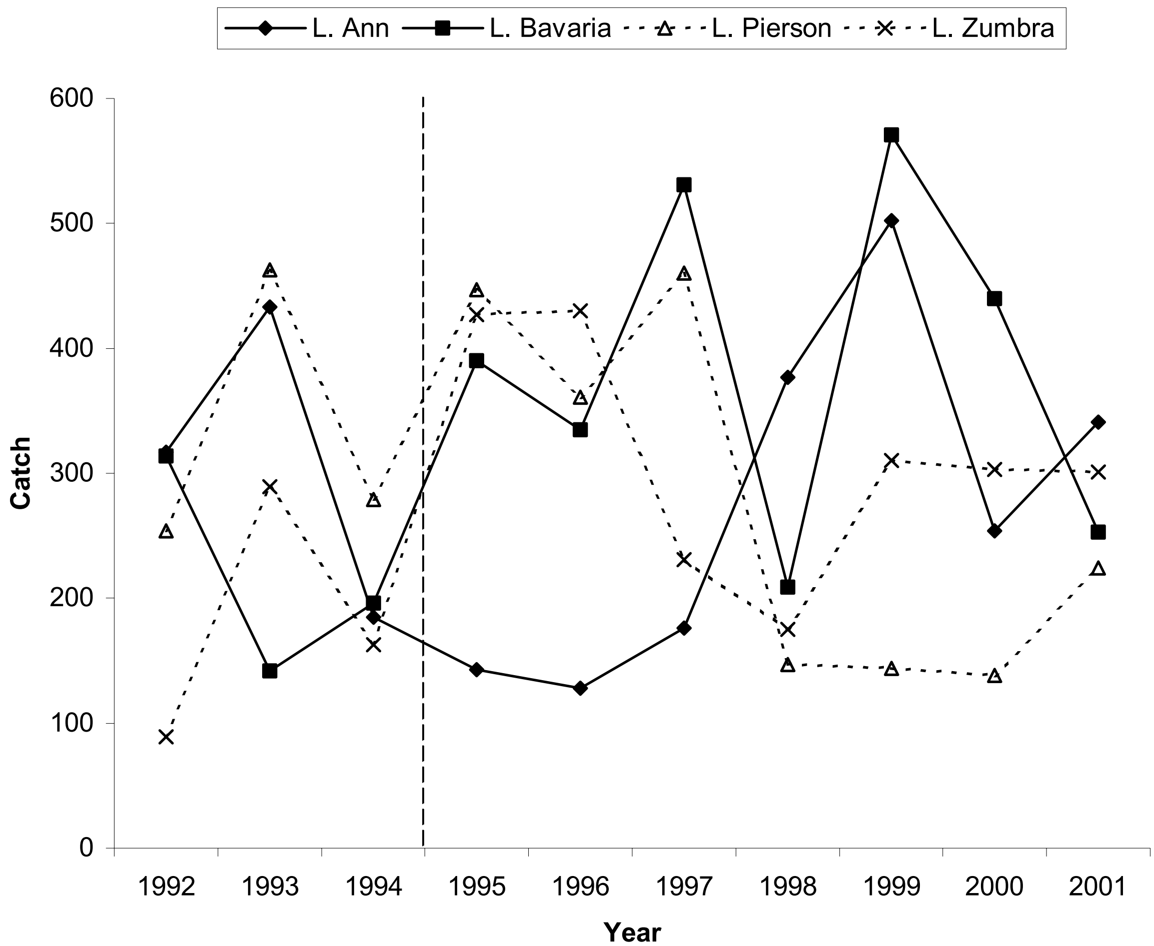

Figure 4. July trap net catches of bluegill in four lakes in Carver County, Minnesota. Experimental regulation lakes are represented by solid lines, control lakes by dotted lines. The vertical line indicates implementation of the experimental largemouth bass regulation in May 1995.

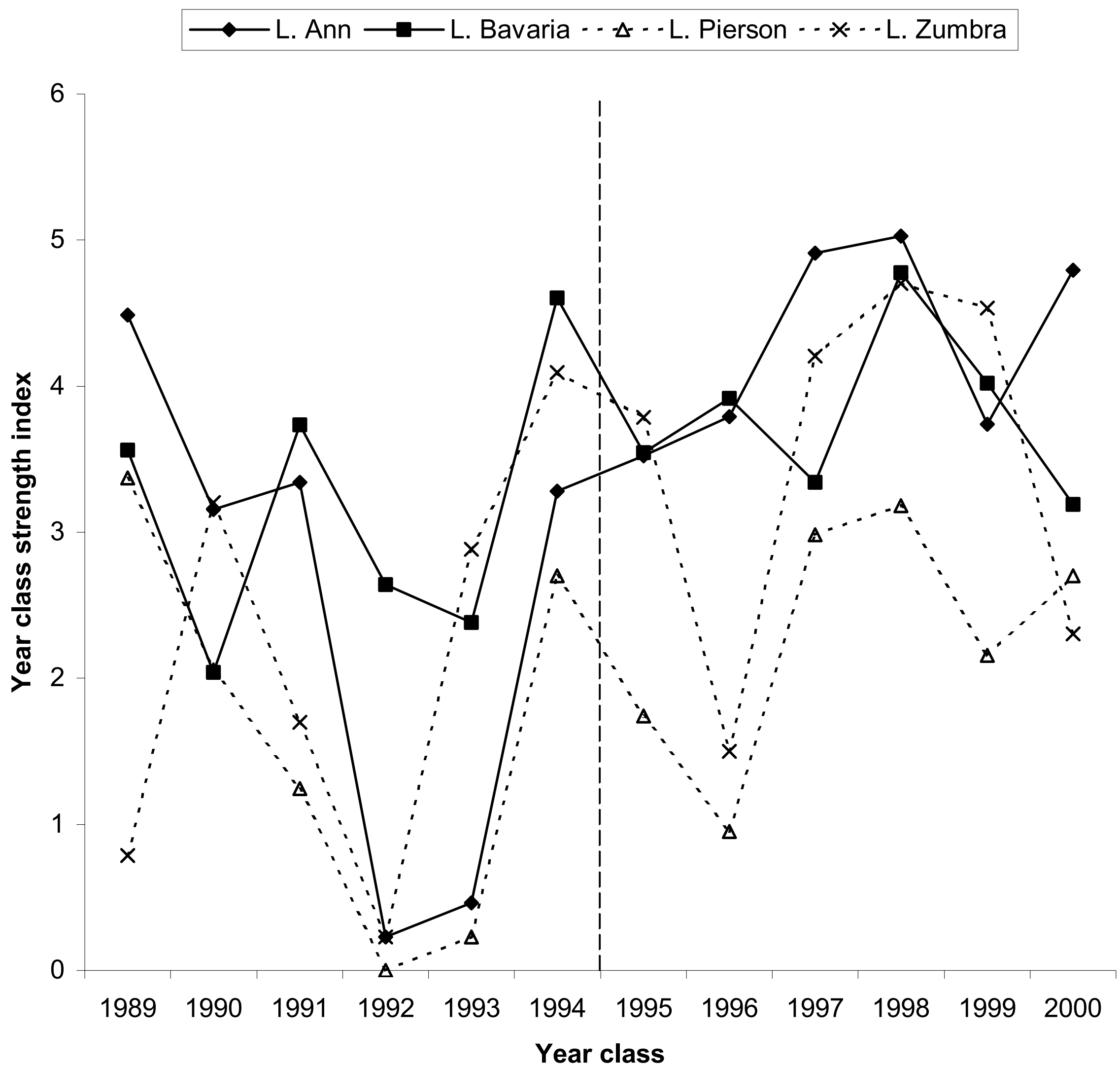

Figure 5. Indices of bluegill year class strengths in four lakes in Carver County, Minnesota, modeled from 1992-2001 trap net catches of age 1-3 fish. Estimates for 1989-1990 and 1999-2000 year classes are less precise than for 1991-1998 year classes due to reduced numbers of ages sampled. Experimental regulation lakes are represented by solid lines, control lakes by dotted lines. The vertical line indicates implementation of the experimental largemouth bass regulation in May 1995.

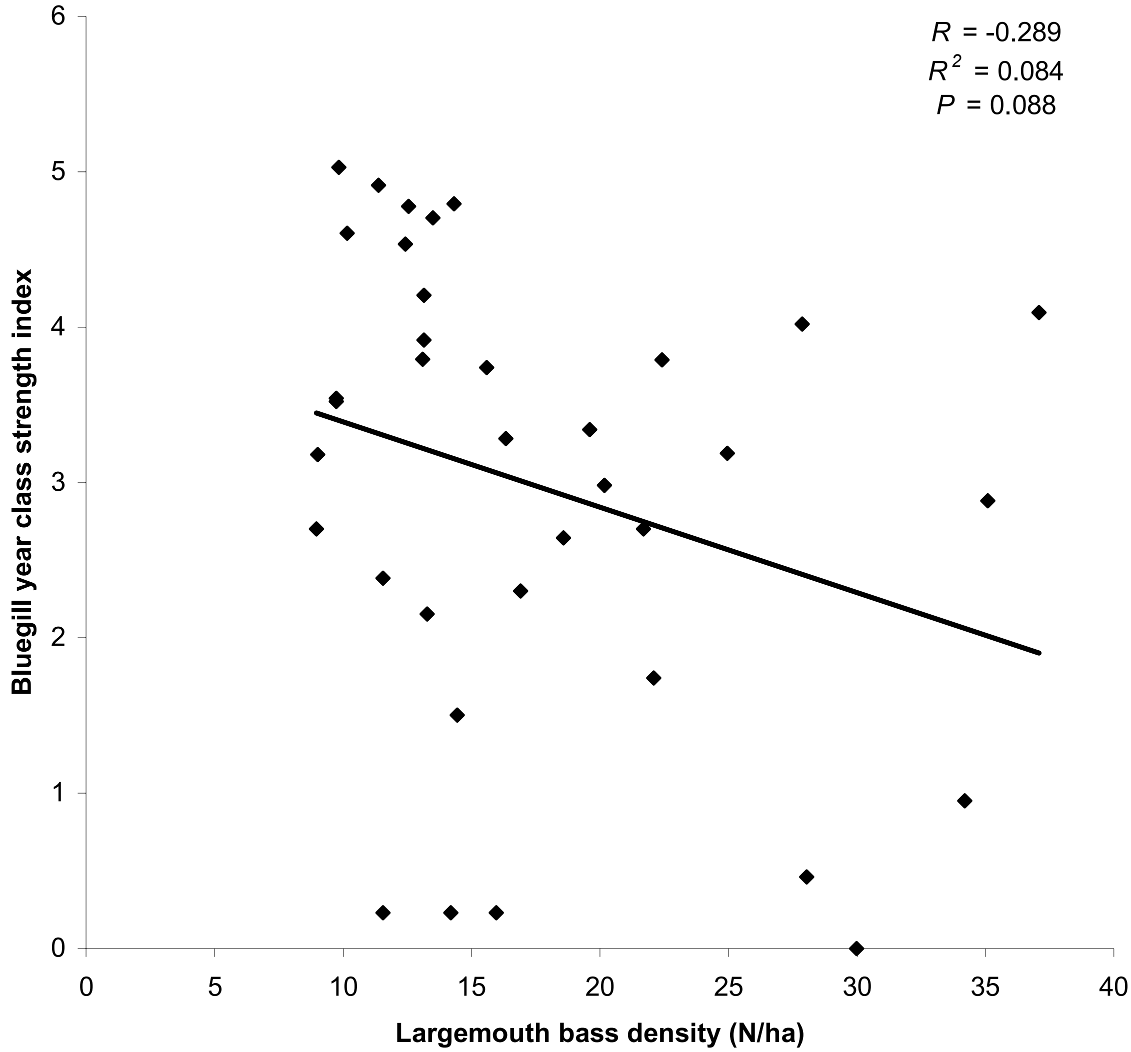

Figure 6. Bluegill year class index (least squares means for t = 1992-2000 year classes) versus population density of largemouth bass ≥ 200 mm TL in year t for four lakes in Carver County, Minnesota.

Table 6. Largemouth bass back-calculated mean total length (mm) at last annulus for four lakes in Carver County, Minnesota. Standard errors are in parentheses; (-) indicates n = 1.

Year	Annulus 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18
L. Ann																	
1992		190 (26)	209 (4)	281 (9)	367 (12)	403 (9)	425 (6)	450 (5)	471 (7)	488 (19)	526 (6)		577 (-)				
1993		191 (4)	226 (3)	279 (5)	333 (10)	401 (8)	437 (7)	453 (7)	469 (6)	451 (6)							
1994		165 (9)	213 (5)	251 (6)	318 (7)	386 (14)	452 (4)	459 (10)	481 (9)	509 (8)	532 (-)			561 (-)			
1995	132 (13)		259 (10)	285 (4)	322 (12)	399 (10)	449 (7)	487 (6)	483 (4)	511 (8)	528 (7)	542 (-)	563 (-)				
1996		193 (30)	239 (6)	266 (7)	332 (5)	363 (6)	403 (7)	428 (8)	432 (18)	485 (4)	503 (4)	513 (13)	537 (6)	512 (-)			
1997			288 (8)	301 (9)	340 (9)	382 (6)	408 (10)	456 (6)	474 (3)	509 (4)	526 (-)		545 (10)				
1998	116 (7)	209 (13)	316 (15)	345 (8)	339 (14)	389 (11)	399 (8)	429 (8)	462 (8)	491 (9)	518 (5)	507 (-)	532 (6)	548 (5)			
1999	95 (7)	178 (5)	223 (4)	268 (12)	349 (12)	387 (10)	402 (6)	436 (8)	458 (8)	477 (9)	476 (8)	526 (9)	481 (-)	535 (7)			
2000		234 (9)	311 (6)	370 (10)	405 (6)	421 (6)	448 (5)	459 (7)	473 (8)	496 (7)	523 (6)	525 (8)	545 (3)	542 (11)	549 (-)	564 (8)	
2001			237 (6)	336 (7)	394 (9)	406 (12)	436 (10)	437 (13)	465 (19)	484 (9)	477 (6)	506 (24)	529 (-)		553 (1)		
L. Bavaria																	
1992		147 (3)	189 (3)	269 (7)	320 (3)	346 (4)	377 (8)	410 (11)	459 (16)	473 (9)	521 (3)	500 (23)					
1993		144 (10)	207 (3)	245 (4)	316 (10)	365 (4)	385 (8)	442 (-)									
1994		146 (3)	191 (6)	251 (6)	309 (6)	373 (8)	400 (8)	440 (5)	474 (8)	497 (-)	515 (-)			523 (-)			
1995	80 (-)	184 (13)	204 (8)	249 (6)	302 (5)	345 (5)	402 (14)	443 (5)	452 (1)	509 (-)		530 (-)					
1996		142 (5)	193 (11)	264 (6)	304 (6)	353 (5)	373 (5)	420 (10)	435 (7)	467 (8)	492 (19)	508 (13)					
1997		139 (-)	185 (5)	243 (9)	326 (5)	370 (5)	410 (6)	433 (7)	463 (10)	494 (5)	525 (11)						
1998	82 (3)	141 (3)	175 (7)	246 (6)	326 (12)	373 (7)	393 (9)	427 (5)	453 (3)	472 (10)	494 (19)	533 (20)					
1999	86 (9)	133 (4)	177 (5)	247 (7)	288 (7)	367 (8)	381 (7)	413 (6)	445 (5)	463 (6)	492 (11)	498 (9)	495 (-)				
2000			207 (5)	228 (5)	267 (5)	296 (6)	338 (7)	393 (8)	432 (9)	435 (9)	477 (17)	487 (17)	515 (9)	530 (15)	552 (-)		
2001			218 (6)	230 (4)	269 (6)	324 (10)	356 (9)	384 (14)	415 (10)	448 (7)	484 (8)	489 (15)	501 (36)	400 (-)			

Table 6. Continued.

Year	Annulus 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	18
L. Pierson																	
1992		134 (5)	209 (3)	242 (3)	308 (9)	364 (2)	382 (2)	398 (4)	442 (11)	480 (8)	519 (-)		549 (-)	520 (-)			
1993		163 (10)	202 (6)	263 (5)	329 (7)	361 (6)	401 (5)	412 (10)	450 (55)								
1994		208 (44)	234 (38)	222 (9)	306 (6)	363 (12)	406 (5)	442 (4)	470 (8)	480 (10)	477 (0)						
1995	158 (4)	148 (13)	170 (8)	249 (7)	286 (7)	363 (6)	385 (8)	422 (8)	457 (6)	450 (7)	476 (-)	500 (-)					
1996		197 (6)	189 (27)	254 (9)	286 (10)	329 (5)	389 (6)	418 (5)	446 (7)	476 (7)	488 (7)	480 (18)	513 (-)				
1997		206 (-)	231 (5)		278 (6)	332 (7)	376 (7)	421 (6)	468 (6)	482 (4)	507 (6)	529 (10)					
1998	110 (7)	201 (7)	242 (11)	291 (5)	325 (14)	346 (10)	374 (9)	394 (6)	446 (6)	447 (5)	489 (10)	519 (-)	538 (-)				
1999	99 (4)	192 (4)	246 (3)	276 (3)	307 (4)	342 (7)	373 (8)	400 (8)	443 (9)	477 (9)	488 (6)	478 (18)	506 (-)		502 (-)		
2000		195 (5)	279 (5)	346 (8)	355 (3)	388 (2)	371 (5)	390 (8)	410 (8)	420 (10)	458 (8)	494 (7)	483 (16)	514 (9)	525 (15)		
2001		206 (-)	260 (5)	308 (6)	342 (12)	370 (4)	393 (7)	416 (8)	419 (10)	434 (12)	456 (14)	496 (16)	484 (20)	507 (-)	511 (2)	535 (-)	520 (-)
L. Zumbra																	
1992		167 (5)	248 (3)	311 (5)	346 (4)	389 (6)	421 (6)	447 (6)	463 (13)	457 (13)	518 (-)		528 (-)				
1993	110 (-)	169 (4)	225 (5)	294 (3)	333 (3)	362 (6)	389 (6)	427 (10)	448 (10)								
1994	154 (3)	152 (-)	210 (12)	232 (6)	330 (6)	369 (9)	410 (5)	428 (9)	443 (5)	475 (7)	504 (10)	503 (15)	523 (1)	535 (5)			
1995	91 (4)	187 (23)	214 (9)	289 (7)	316 (7)	379 (7)	415 (7)	435 (7)	462 (8)	480 (8)	499 (8)	512 (7)	523 (-)	523 (-)			
1996	128 (-)	169 (9)	213 (7)	270 (10)	330 (6)	363 (6)	401 (8)	419 (9)	449 (8)	458 (6)	467 (6)	498 (6)	507 (3)	515 (-)			
1997		186 (6)	249 (6)	313 (11)	380 (11)	376 (4)	409 (6)	435 (10)	454 (22)	466 (10)	474 (5)	507 (14)	511 (6)				
1998	113 (6)	229 (5)	290 (6)	330 (5)	370 (7)	391 (6)	408 (6)	426 (4)	449 (13)	479 (7)	472 (16)	507 (4)	492 (-)	535 (-)			
1999	129 (4)	204 (5)	269 (4)	323 (5)	355 (5)	383 (4)	408 (4)	432 (6)	423 (26)	465 (11)		500 (29)	538 (6)	539 (24)	547 (-)		
2000		189 (3)	260 (6)	335 (6)	389 (7)	408 (7)	436 (10)	428 (13)	467 (7)	463 (5)	483 (7)	514 (1)	532 (5)		540 (-)		
2001			217 (7)	251 (9)	304 (11)	344 (11)	375 (13)	386 (11)	419 (29)	458 (8)	481 (11)	472 (7)	477 (-)	502 (16)	532 (-)		

and after (1995-1996 year classes) the regulation change, while mean length in pooled control lakes increased from 329 mm before to 347 mm after. The mean in Lake Ann increased from 350 mm before to 400 mm after, but the mean in Lake Bavaria decreased from 318 mm before to 268 mm after. None of the overall period X treatment interactions were significant for any of the mean lengths at annuli (Table 2).

Mean back-calculated lengths at last annuli of bluegill usually did not reach quality size (150 mm) until annulus 5 or older (Table 7). Lengths at annuli were generally between the first and third quartiles for Minnesota Lake Class 24 lakes (Tomcko and Pierce 1997), indicating growth was typical for this lake class. Mean lengths never equaled or exceeded the minimum preferred size of 200 mm, even though we sampled fish up to age 10. Estimated asymptotic lengths were often 165 - 199 mm except for Lake Bavaria, where von Bertalanffy growth curves consistently suggested the potential for fish to reach preferred size if they could survive to old ages (Table 8). Similar to largemouth bass, comparisons of mean lengths before and after the regulation changes were limited to annuli 3-5. Mean lengths at annuli 3-5 significantly increased in all lakes after the experimental regulations (Table 2), probably due to improved thermal conditions following the unusually cool 1992-1993 growing seasons. Mean length of bluegill at annulus 3 in the experimental lakes increased from 99 mm before the regulation change (1989-1991 year classes) to 104 mm after the regulation change (1996-1998 year classes), while mean length in the pooled control lakes increased from 89 mm before to 121 mm after. The mean in Lake Ann increased from 101 mm before to 110 mm after, and the mean in Lake Bavaria increased from 99 mm before to 104 mm after. The control lakes increased significantly more than the experimental lakes (Figure 7; Table 2). Mean length of bluegill at annulus 4 in pooled experimental lakes increased from 125 mm before the regulation change (1988-1990 year classes) to 136 mm after the regulation change (1995-1997 year classes), while mean length in pooled control lakes increased from 113 mm before to 142 mm after. The mean in Lake Ann increased from 130 mm before to 140 mm after, and the mean in Lake Bavaria increased from 121 mm before to 132 mm after. Mean length of bluegill at annulus 5 in pooled experimental lakes increased from 141 mm before the regulation change (1988-1989 year classes) to 156 mm after the regulation change (1995-1996 year classes), while mean length in pooled control lakes increased from 136 mm before to 157 mm after. The mean in Lake Ann increased from 144 mm before to 155 mm after, and the mean in Lake Bavaria increased from 138 mm before to 157 mm after. The period X treatment interactions were not significant for mean lengths at annuli 4-5 (Table 2).

Size Structure of Largemouth Bass and Bluegill

Estimates of PSD and RSD of largemouth bass adjusted for size-selectivity of the electrofishing samples were 2-10 units lower than unadjusted estimates because 200-299 mm fish were captured less efficiently than larger fish (Table 9; Appendix 1). Adjusted PSD ranged from 33 in Lake Bavaria in 1993, to 89 in Lake Ann in 1998; adjusted RSD-P ranged from 8 in Lake Bavaria in 1993, to 61 in Lake Ann in 2000; and adjusted RSD-M ranged from 0 in four cases before 1996, to 12 in Lake Ann in 1998 (Table 9). No trophy-sized (≥ 630 mm) largemouth bass were ever captured. Mean adjusted PSD in pooled experimental lakes increased from 55 before the experimental regulations (1992-1995) to 71 after the experimental regulations (1998-2001), while mean adjusted PSD in pooled control lakes increased from 53 to 63. Mean adjusted PSD in Lake Ann increased from 59 before to 76 after, and mean adjusted PSD in Lake Bavaria increased from 51 before to 66 after. Mean adjusted RSD-P in pooled experimental

Table 7. Bluegill back-calculated mean total length (mm) at last annulus for four lakes in Carver County, Minnesota. Standard errors are in parentheses. (-) indicates n = 1.

	Annulus																			
Year	1		2		3		4		5		6		7		8		9		10	
											L. Ann									
1992	48	(0.9)	73	(1.5)	97	(1.8)	129	(2.7)	146	(2.7)	152	(2.3)								
1993			81	(2.0)	100	(2.1)	122	(1.2)	141	(2.1)	156	(1.9)	170	(2.8)						
1994	39	(-)			105	(1.7)	138	(3.5)	142	(2.5)	157	(3.1)								
1995	48	(1.3)			93	(-)	127	(2.1)	148	(3.6)	160	(2.4)	168	(4.5)						
1996	47	(0.9)	82	(1.3)	107	(-)	124	(5.7)	156	(3.9)	170	(3.0)	177	(-)						
1997	45	(1.0)	80	(1.3)	116	(2.0)	145	(6.9)	162	(4.2)	161	(2.3)	167	(4.8)						
1998	45	(1.2)	83	(1.3)	115	(1.4)	144	(2.2)	157	(-)	170	(1.5)	183	(3.4)	187	(4.1)	199	(-)		
1999	56	(1.9)	90	(1.4)	119	(1.6)	146	(2.6)	169	(-)	161	(-)	168	(0.7)						
2000	50	(2.4)	80	(3.0)	109	(4.0)	140	(2.8)	154	(-)	157	(-)								
2001	44	(1.3)	72	(1.0)	102	(2.6)	134	(4.8)	155	(2.5)	168	(-)	193	(-)						
											L. Bavaria									
1992	48	(0.7)	68	(0.9)	83	(0.8)	106	(1.5)	136	(3.8)	148	(2.3)	156	(-)						
1993	39	(1.9)	80	(1.4)	106	(4.5)	122	(2.0)	139	(3.4)	154	(2.0)	172	(1.8)						
1994	38	(1.6)	69	(0.8)	105	(2.0)	135	(7.9)	158	(3.1)	167	(3.3)	165	(4.4)						
1995	43	(0.9)	70	(1.3)	98	(1.7)	134	(2.3)	156	(6.3)	179	(2.2)	175	(5.8)						
1996	40	(0.9)	75	(1.4)	99	(7.2)	131	(3.4)	154	(2.6)	174	(3.1)	182	(3.3)	170	(-)				
1997	44	(1.0)	67	(1.8)	115	(1.9)	142	(3.8)	157	(2.8)	171	(2.0)	183	(2.4)	189	(8.5)	193	(-)		
1998	42	(0.9)	69	(1.3)	99	(1.3)	145	(1.7)	160	(6.1)	181	(-)	172	(-)						
1999	51	(1.6)	75	(2.3)	105	(1.8)	141	(1.7)	163	(2.3)	170	(-)					186	(-)		
2000	51	(2.6)	73	(3.0)	97	(2.1)	127	(4.1)	156	(3.8)	177	(3.9)								
2001	43	(1.4)	62	(1.9)	92	(2.2)	127	(2.2)	158	(5.3)	166	(3.4)								

Table 7. Continued.

Year	Annulus 1		2		3		4		5		6		7		8		9		10	
L. Pierson																				
1992			61	(2.1)	93	(1.9)	118	(2.8)	136	(2.4)	148	(2.3)	160	(2.9)	162	(-)				
1993			50	(-)	88	(3.3)	116	(1.9)	143	(2.2)	153	(1.9)	165	(2.3)	174	(2.9)				
1994					79	(1.5)	109	(3.4)	134	(2.5)	146	(-)								
1995	43	(1.7)	85	(-)			117	(7.3)	136	(2.4)	157	(4.5)	182	(-)						
1996	47	(1.6)	85	(2.4)					129	(3.2)	131	(2.3)	159	(1.6)						
1997			77	(4.2)	99	(3.5)	119	(1.5)	112	(1.6)	134	(2.2)	143	(2.8)	164	(1.5)				
1998	47	(1.4)	80	(3.4)	102	(3.5)	135	(2.6)	144	(1.0)	147	(-)	148	(3.5)	149	(2.8)	175	(3.0)		
1999	52	(2.0)	84	(2.3)	128	(6.7)	139	(3.5)	157	(1.6)	150	(3.9)	164	(3.6)	162	(4.2)	162	(7.4)	170	(15.3)
2000			78	(4.8)	112	(5.8)	133	(2.9)	152	(4.0)	155	(6.3)	161	(-)	151	(4.3)	177	(2.9)	176	(3.3)
2001	42	(2.5)	78	(2.3)	119	(3.3)	144	(5.5)	163	(-)	178	(3.9)	188	(-)					186	(4.2)
L. Zumbra																				
1992	41	(1.9)	66	(1.2)	107	(3.8)	120	(4.5)	137	(2.1)	151	(2.8)	154	(3.4)	164	(-)				
1993			58	(1.9)	82	(1.4)	108	(1.9)	126	(1.4)	137	(2.4)	153	(3.2)	157	(3.3)	166	(4.8)		
1994	38	(1.4)			83	(4.1)	106	(1.7)	140	(2.7)	150	(3.4)	163	(3.9)	173	(-)	166	(-)		
1995	51	(1.1)	83	(7.3)	77	(-)	106	(2.1)	136	(3.0)	158	(2.8)	165	(2.3)	179	(1.5)	195	(-)	176	(-)
1996	49	(1.0)	78	(1.5)	114	(6.2)	108	(-)	128	(3.4)	143	(1.9)	151	(-)	160	(-)				
1997			77	(1.5)	106	(1.6)	136	(-)	126	(-)	149	(1.6)	158	(1.8)						
1998	52	(1.9)	82	(0.9)	105	(1.3)	134	(2.3)	144	(9.0)	149	(0.7)	167	(-)						
1999	51	(1.7)	98	(2.4)	126	(2.4)	137	(2.4)	152	(3.3)	163	(1.9)	177	(-)						
2000	46	(1.4)	87	(1.9)	124	(1.2)	141	(1.0)	146	(2.2)	160	(7.9)	171	(1.9)	191	(-)				
2001	46	(3.3)	72	(2.2)	118	(2.7)	160	(6.1)	165	(4.6)	178	(-)	178	(11.9)						

Table 8. Von Bertalanffy growth parameters and corresponding age-at-length estimates calculated from mean back-calculated lengths (mm) at last annuli of bluegill for four lakes in Carver County, Minnesota. All available annuli were used. Parameters could not be estimated for the 1994 Lake Pierson sample using FISHPARM 3.0. Definitions: t_{150} = mean age at 150 mm, t_{200} = mean age at 200 mm.

	Year of sample									
Parameter	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Ann					
L_∞	234	307	185	252	253	185	216	186	200	338
K	0.178	0.102	0.331	0.158	0.174	0.382	0.269	0.379	0.278	0.117
t_0	-0.216	-0.969	0.293	-0.275	-0.191	0.337	0.151	0.112	0.026	-0.146
t_{150}	5.5	5.6	5.3	5.5	5.0	4.7	4.5	4.5	5.0	4.9
t_{200}	10.7	9.4		9.7	8.8		9.7			7.5
					L. Bavaria					
L_∞	392	215	202	259	210	216	230	211	1.77E+05	566
K	0.067	0.218	0.295	0.180	0.266	0.272	0.239	0.269	1.47E-04	0.059
t_0	-0.833	0.004	0.382	0.108	0.286	0.292	0.292	0.119	-0.869	-0.195
t_{150}	6.3	5.5	5.0	4.9	5.0	4.6	4.7	4.7	4.9	5.1
t_{200}	9.8	12.4	16.6	8.3	11.7	9.8	8.8	11.2	6.8	7.2
					L. Pierson					
L_∞	181	196		516	186	2555	171	169	174	201
K	0.325	0.314		0.054	0.221	0.005	0.339	0.468	0.417	0.355
t_0	0.752	1.076		-0.876	-0.449	-4.105	0.084	0.267	0.554	0.424
t_{150}	6.2	5.7		5.5	7.0	7.2	6.2	5.0	5.3	4.3
t_{200}				8.2		11.2				16.0
					L. Zumbra					
L_∞	184	193	216	258	183	168	198	187	201	209
K	0.281	0.229	0.191	0.131	0.235	0.379	0.247	0.360	0.294	0.330
t_0	0.172	0.483	0.102	-0.560	-0.393	0.354	-0.212	0.067	0.068	0.372
t_{150}	6.2	7.0	6.3	6.1	6.9	6.3	5.5	4.6	4.7	4.2
t_{200}			13.8	10.9					17.5	10.0

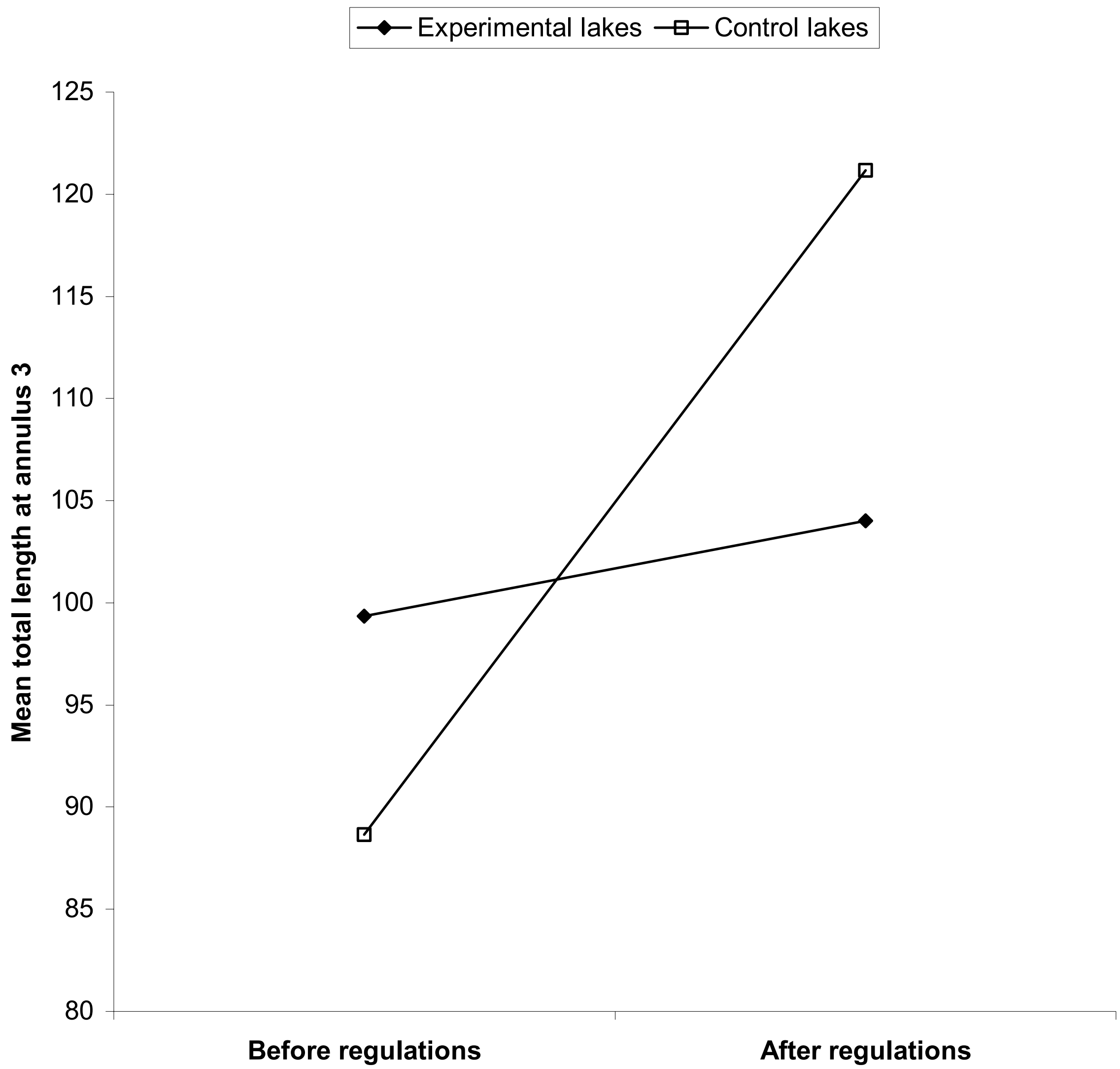

Figure 7. Bluegill mean total length at annulus 3 in two experimental regulation lakes and two control lakes before (1989-1991 year classes) and after (1996-1998 year classes) implementation of an experimental regulation prohibiting harvest of largemouth bass.

Table 9. Proportional stock density (PSD), relative stock density – preferred (RSD-P), and relative stock density – memorable (RSD-M) of largemouth bass in four lakes in Carver County, Minnesota. No trophy-sized (≥ 630 mm) fish were ever captured. Sample sizes (N) represent numbers of stock size (≥ 200 mm) fish measured. Unadjusted values were calculated from raw length frequency data. Adjusted values account for size selectivity of the electrofishing samples.

	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Ann					
N	112	150	128	118	197	149	120	226	251	171
PSD (unadjusted)	74.1	55.3	48.4	72.0	84.8	86.6	95.0	76.1	88.4	65.5
PSD (adjusted)	69.7	52.0	45.5	67.7	79.7	81.4	89.3	71.5	83.1	61.6
RSD-P (unadjusted)	66.1	36.0	28.9	49.2	42.6	38.3	62.5	67.7	70.1	42.7
RSD-P (adjusted)	57.2	31.2	25.0	42.6	36.9	33.1	54.1	58.6	60.7	37.0
RSD-M (unadjusted)	4.5	0.7	3.1	6.8	8.1	5.4	13.3	4.9	7.2	4.1
RSD-M (adjusted)	3.9	0.6	2.7	5.9	7.0	4.7	11.6	4.2	6.2	3.5
					L. Bavaria					
N	171	75	150	171	254	185	201	338	446	311
PSD (unadjusted)	73.7	34.7	50.0	59.1	63.4	85.9	70.6	73.4	79.6	56.6
PSD (adjusted)	69.6	32.8	47.2	55.8	59.9	81.2	66.8	69.3	75.2	53.5
RSD-P (unadjusted)	22.2	9.3	26.0	15.8	17.3	36.8	41.8	53.0	54.7	31.2
RSD-P (adjusted)	18.1	7.6	21.2	12.9	14.1	30.0	34.1	43.2	44.6	25.4
RSD-M (unadjusted)	2.3	0.0	1.3	0.6	0.8	2.2	2.0	1.8	2.0	1.6
RSD-M (adjusted)	1.9	0.0	1.1	0.5	0.6	1.8	1.6	1.4	1.6	1.3
					L. Pierson					
N	308	156	283	328	336	268	205	352	292	250
PSD (unadjusted)	54.5	67.9	57.2	52.7	76.5	70.5	75.6	74.7	73.6	81.2
PSD (adjusted)	49.0	61.1	51.5	47.4	68.8	63.4	68.0	67.2	66.2	73.0
RSD-P (unadjusted)	25.6	37.2	33.9	31.7	34.2	38.4	34.1	31.8	40.4	36.4
RSD-P (adjusted)	23.2	33.6	30.7	28.7	31.0	34.8	30.9	28.8	36.6	32.9
RSD-M (unadjusted)	1.0	0.0	0.4	0.0	0.3	2.2	2.0	1.7	5.1	2.4
RSD-M (adjusted)	0.9	0.0	0.3	0.0	0.3	2.0	1.8	1.5	4.6	2.2
					L. Zumbra					
N	198	227	369	345	311	189	174	304	345	308
PSD (unadjusted)	55.1	64.3	61.8	57.4	85.5	70.4	75.3	65.5	62.0	50.3
PSD (adjusted)	50.0	58.5	56.2	52.2	77.7	64.0	68.4	59.5	56.4	45.7
RSD-P (unadjusted)	25.8	18.9	27.1	22.6	33.1	41.3	36.2	35.5	39.7	26.9
RSD-P (adjusted)	23.2	17.1	24.5	20.4	29.9	37.2	32.7	32.1	35.8	24.3
RSD-M (unadjusted)	1.0	0.0	2.4	2.3	0.3	1.1	1.1	2.3	2.6	1.3
RSD-M (adjusted)	0.9	0.0	2.2	2.1	0.3	1.0	1.0	2.1	2.4	1.2

lakes increased from 27 before the experimental regulations (1992-1995) to 45 after the experimental regulations (1998-2001), while mean adjusted RSD-P in pooled control lakes increased from 25 to 32. Mean adjusted RSD-P in Lake Ann increased from 39 before to 53 after, and mean adjusted RSD-P in Lake Bavaria increased from 15 before to 37 after. Mean adjusted RSD-M in pooled experimental lakes increased from 2 before the experimental regulations (1992-1995) to 4 after the experimental regulations (1998-2001), while mean adjusted RSD-M in pooled control lakes increased from 1 to 2. Mean adjusted RSD-M in Lake Ann increased from 3 before to 6 after, and mean adjusted RSD-M in Lake Bavaria increased from 1 before to 2 after. Although the quality of the largemouth bass size structure tended to increase more in the experimental lakes than in the control lakes, the period X treatment interactions were not statistically significant for PSD, RSD-P, or RSD-M (Table 2).

Proportional stock density of bluegill ranged from 6 in Lake Ann in 1999, to 88 in Lake Pierson in 2000 (Table 10). Relative stock density – preferred was less than 1.0 (usually zero) except for Lake Ann in 1998 (RSD-P = 2.3) and Lake Bavaria in 1996 (RSD-P = 1.5). There was no correlation between bluegill trap net catch and PSD in any of the study lakes (Figure 8). Mean PSD in the experimental lakes decreased from 52 in the 3 sampling years before the experimental regulations (1992-1994), to 25 in the last 3 years of the study (1999-2001), while the mean PSD in the control lakes increased from 38 to 57. Mean PSD in Lake Ann decreased from 54 before to 11 after, and mean PSD in Lake Bavaria decreased from 51 before to 38 after. There was no significant period X treatment interaction (Table 2).

With the exception of Lake Bavaria in 1993, from 1992-2001 the largemouth bass PSD in all study lakes was in the moderate to high range (Gabelhouse 1984; Figure 9). The low value for Lake Bavaria in 1993 may have been unrepresentative due to a small sample size (Table 9). Bluegill PSD was also generally in the moderate to high range (Anderson 1980), although Lake Ann was in the low range from 1999-2001 (Figure 9). There was no significant correlation between largemouth bass PSD and bluegill PSD in experimental regulation Lakes Ann and Bavaria (Figure 9). Of the two lakes with standard regulations, there was a significant positive (P = 0.093) correlation in Lake Pierson, and a significant negative correlation (P = 0.096) in Lake Zumbra (Figure 9). Similar to PSD, all the largemouth bass RSD-P values for 1992-2001 were in the moderate to high range (Gabelhouse 1984), except for Lake Bavaria in 1993 (Figure 10). There was a strong negative correlation between largemouth bass RSD-P and bluegill PSD in Lake Ann, but no significant correlations in the other lakes (Figure 10). Use of unadjusted rather than adjusted values of largemouth bass PSD and RSD-P would have shifted all data points slightly to the right in Figures 9-10, but would have made no difference to overall conclusions.

Creel Survey

Most anglers initially accepted the regulation requiring immediate release of largemouth bass. During the first two years of the regulation, 94% of respondents at Lake Ann and 95% at Lake Bavaria said they favored the regulation if it would yield larger panfish. Three percent at Lake Ann and 2% at Lake Bavaria opposed the regulation, and 3% at each lake had no opinion.

Largemouth bass and panfish (sunfish and black crappie) were generally the species most sought by anglers on the study lakes (Table 11). There were also substantial northern pike fisheries, especially on Lake Pierson. Percentages of angling parties seeking largemouth bass ranged from 21% on Lake Bavaria in 1994, to 60% on Lake Zumbra in 1992. There was no significant

Table 10. Proportional stock density (PSD) and relative stock density – preferred (RSD-P) of bluegill in four lakes in Carver County, Minnesota. Sample sizes (N) represent numbers of stock-size (≥ 80 mm) fish measured.

	Year									
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Ann					
N	274	433	184	127	62	152	174	429	230	213
PSD	27.0	72.7	63.0	59.8	40.3	63.8	32.8	5.8	9.1	18.8
RSD-P	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.4	0.5
					L. Bavaria					
N	259	138	191	220	269	517	190	379	418	231
PSD	31.3	63.0	57.6	54.5	67.7	86.8	37.9	41.2	47.1	25.5
RSD-P	0.0	0.0	0.0	0.0	1.5	0.6	0.0	0.0	0.0	0.0
					L. Pierson					
N	252	461	263	441	357	460	137	127	137	219
PSD	42.5	37.7	23.6	53.1	43.7	68.5	68.6	59.8	87.6	67.1
RSD-P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
					L. Zumbra					
N	80	286	155	408	397	230	162	272	253	295
PSD	63.8	19.2	40.0	41.2	24.7	42.2	22.2	40.1	49.0	35.6
RSD-P	0.0	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0

period X treatment interaction for percentages of angling parties seeking largemouth bass (Table 2). Percentages of angling parties seeking panfish ranged from 18% on Lake Zumbra in 1992, to 73% on Lake Bavaria in 2000 and 2001. Similar to largemouth bass, there was no significant period X treatment interaction for percentages of angling parties seeking panfish (Table 2).

Total angling effort ranged from 50 angler·h/ha on Lake Pierson in 1993, to 153 angler·h/ha on Lake Ann in 1993, and effort tended to be higher in the experimental lakes than in the control lakes (Table 12). There was no significant period X treatment interaction for total angling effort (Table 2).

The experimental regulations reduced largemouth bass harvest, but did not eliminate it (Table 13). Under the restrictive regulation implemented in 1995, the average harvest estimates of largemouth bass from Lakes Ann and Bavaria declined 68% and 88% from pre-regulation years, respectively. For the same period, largemouth bass harvest estimates increased 25% at Lake Pierson and decreased 21% at Lake Zumbra. The proportion of angling parties interviewed at Lake Ann in 1996 and 1997 that harvested largemouth bass was 3.2% (Table 14) -- a decline of 73% from the 12% of parties that had harvested bass (legally) before the regulation was implemented. At Lake Bavaria, 2.1% of the parties interviewed harvested largemouth bass -- a decline of 76%. Anglers were observed keeping largemouth bass illegally at Lakes Ann and Bavaria in 2000-2001, but no attempt was made to quantify illegal harvest because anglers generally released the fish upon being interviewed.

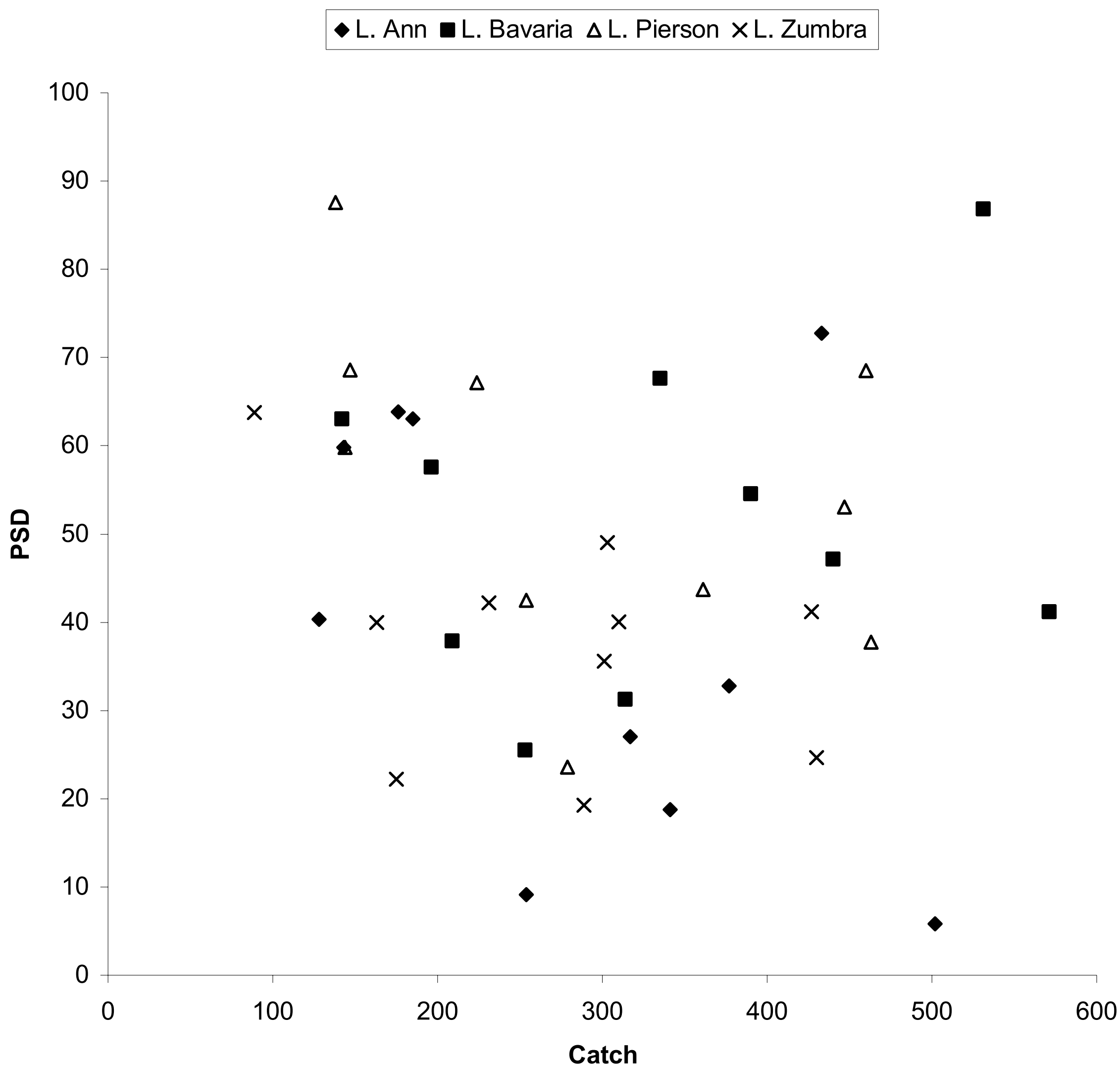

Figure 8. Bluegill PSD versus July trap net catch of bluegill for four lakes in Carver County, Minnesota.

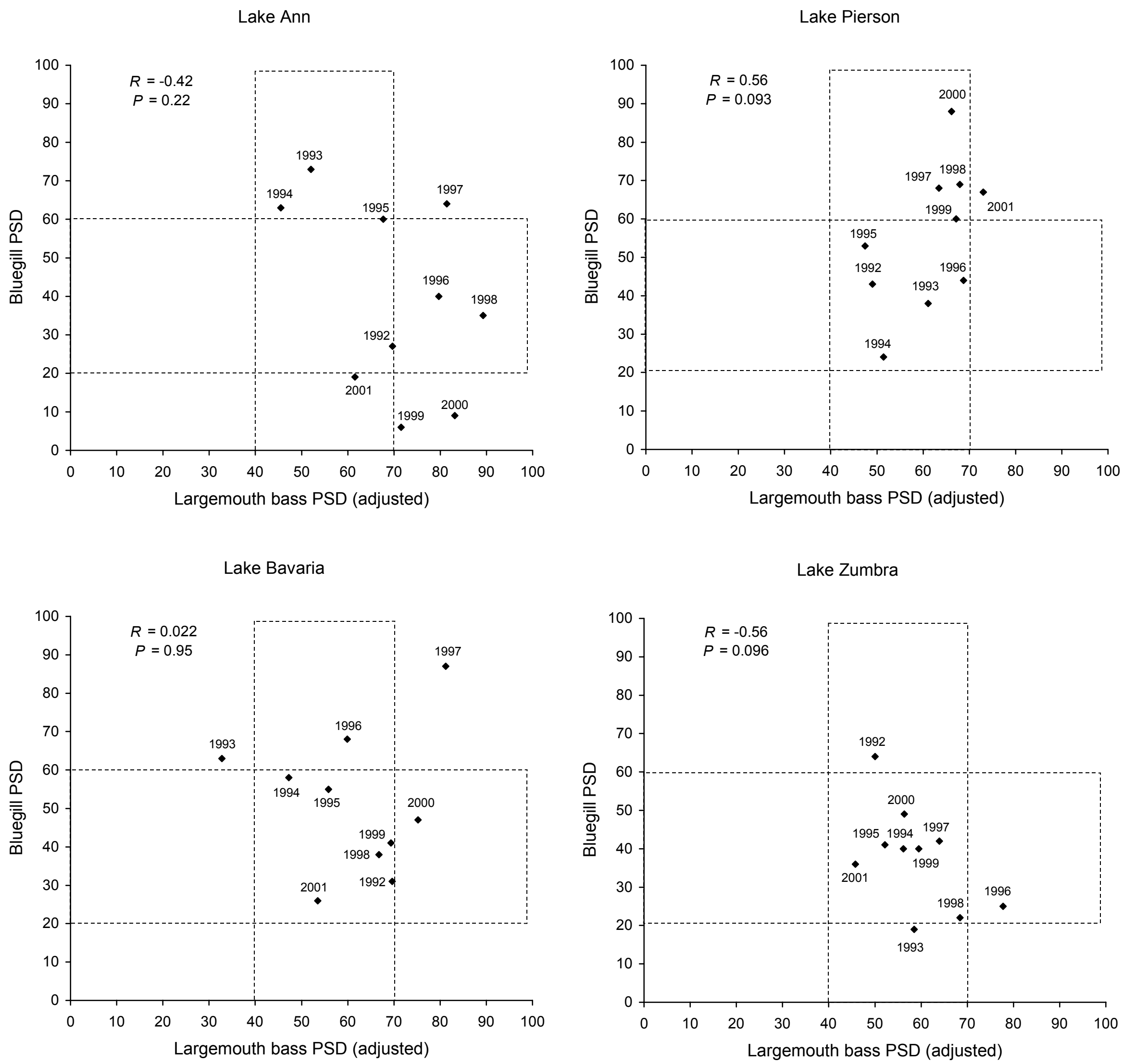

Figure 9. Bluegill PSD versus largemouth bass PSD at four lakes in Carver County, Minnesota, 1992-2001. Largemouth bass PSD was adjusted for size selectivity of the electrofishing samples. Dashed rectangles enclose ranges indicative of balance according to Anderson (1980).

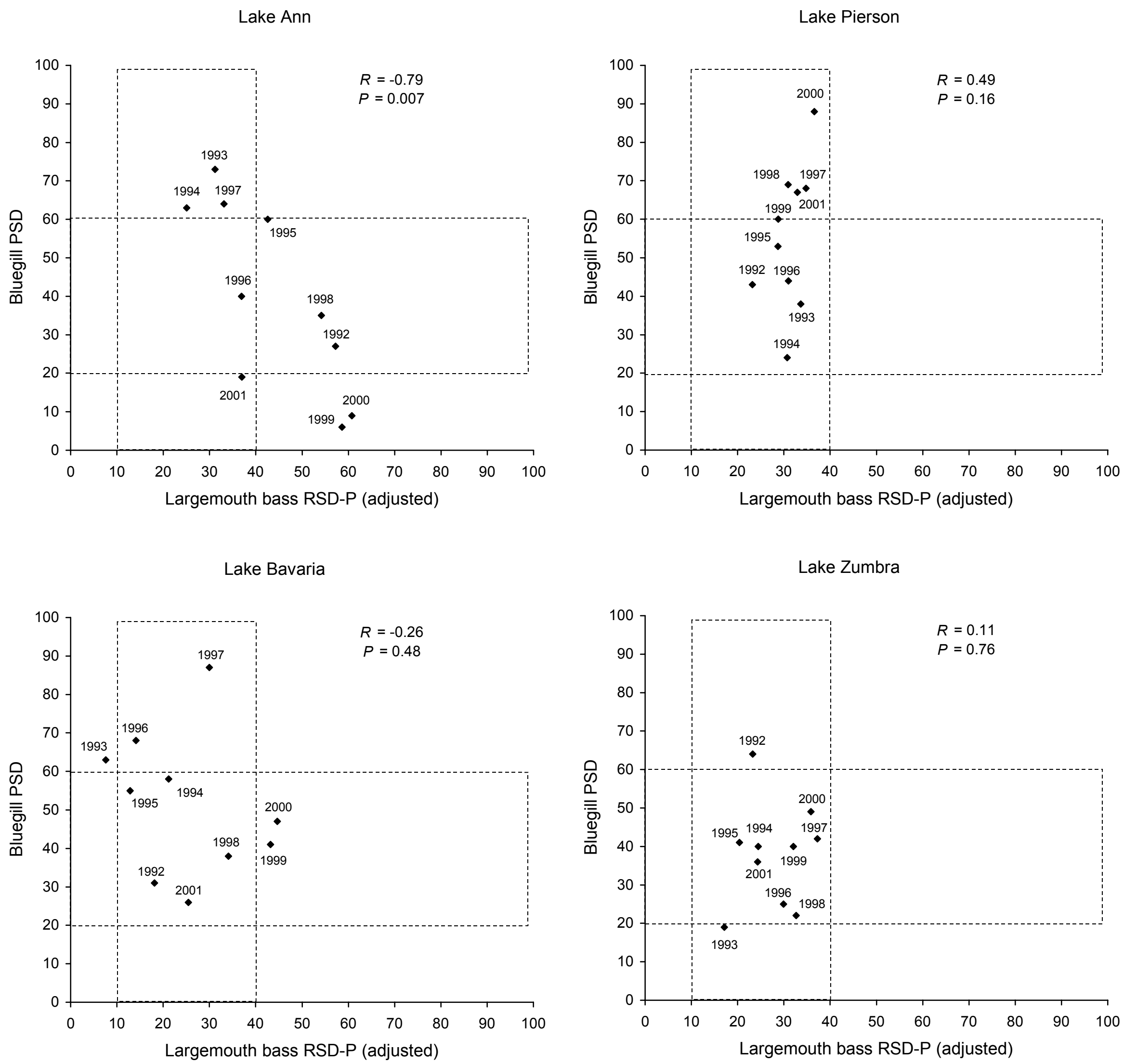

Figure 10. Bluegill PSD versus largemouth bass RSD-P at four lakes in Carver County, Minnesota, 1992-2001. Largemouth bass RSD-P was adjusted for size selectivity of the electrofishing samples. Dashed rectangles enclose ranges indicative of balance according to Anderson (1980) and Gabelhouse (1984).

Table 11. Percentages of angling parties seeking various species or groups of species in four lakes in Carver County, Minnesota during the open water season (April – November). Up to two preferences per party were recorded during the survey, so totals exceed 100%.

Year	Number of interviews	Largemouth Bass	Northern Pike	Sunfish [a]	Crappie [b]	Panfish [c]	Other [d]	No preference
				L. Ann [e]				
1992	113	42	6	5	7	44		22
1993	134	36	13	23	6	53		20
1994	168	40	7	39	20	58		18
1995	112	31	9[f]	42	17	61	1	23
1996	135	56	19	27	9	37		13
2000	222	43	20	22	7	36		25
2001	181	40	20	24	6	29		30
				L. Bavaria [e]				
1992	159	31	16	8	16	53		21
1993	170	30	6	26	16	72		10
1994	193	21	12	44	30	69		16
1995	130	29	12	42	22	65		9
1996	162	23	20	37	28	64		11
2000	232	28	17	50	18	73		6
2001	173	32	12	45	28	73		11
				L. Pierson				
1992	215	28	29[f]	11	7	52		9
1993	125	30	31[g]	14	11	46		15
1994	161	26	35[f]	24	21	43		16
1995	146	47	47[g]	18	12	34	1	8
1996	185	49	48[g]	22	8	32	1	7
2000	255	40	48[g]	17	10	31	3	12
2001	191	27	41[g]	23	15	38	3	16
				L. Zumbra				
1992	134	60	27	1	6	18		13
1993	163	53	40	15	8	30		7
1994	229	45	34	29	10	36	1	7
1995	209	44	34	26	11	37	1	11
1996	158	51	34	20	11	28	1	12
2000	93	57	24	20	9	35		11
2001	107	59	20	26	20	46		8

[a] Sunfish and bluegill.
[b] White crappie and black crappie.
[c] Panfish, sunfish, bluegill, white crappie, and black crappie.
[d] Bullhead, carp, and walleye.
[e] Immediate release of largemouth bass required beginning May 1995.
[f] Includes muskellunge.
[g] Includes muskellunge and tiger muskellunge.

Table 12. Estimates of open-water angling effort on four lakes in Carver County, Minnesota. The 1992-1994 data were before the experimental largemouth bass regulation, and the 1996 and 2000-2001 data were after regulation implementation. The 1995 values were excluded from analyses of potential regulation effects in order to have equal numbers of years before and after, and because 1995 was a transitional year.

	L. Ann[a]			L. Bavaria[a]			L. Pierson			L. Zumbra		
Year	Angler hours	SE	Hours/ ha	Angler hours	SE	Hours/ ha	Angler hours	SE	Hours/ ha	Angler hours	SE	Hours/ ha
1992	4,248	696	90	7,870	1,148	120	10,043	1,616	80	6,256	980	87
1993	7,175	1,193	153	8,662	1,061	132	6,304	1,020	50	7,981	910	110
1994	5,923	726	126	9,225	1,119	140	7,584	1,229	61	10,192	1,115	141
1995	5,331	994	113	6,413	788	97	6,762	1,198	54	8,487	1,018	118
1996	6,433	729	137	7,514	1,144	114	7,910	1,055	63	6,896	971	96
2000	6,979	957	148	7,800	971	118	9,820	1,221	79	3,760	688	52
2001[b]	6,212	908	132	6,576	849	100	8,362	1,229	67	4,635	803	64
1992-94 mean	5,782	872	123	8,586	1,109	131	7,977	1,288	64	8,143	1,002	113
1996, 2000-2001 mean	6,541	865	139	7,297	988	111	8,697	1,168	70	5,097	821	71

[a] Immediate release of largemouth bass required beginning in 1995.
[b] Adjusted for lack of October-November data.

Sunfish (primarily bluegill) usually composed the majority of the open-water harvest on all study lakes (Table 13). Sunfish harvest estimates ranged from 5/ha on Lake Zumbra in 1992, to 202/ha on Lake Bavaria in 2000. There were large differences between and within lakes, but there was no significant period X treatment interaction (Table 2). Largemouth bass harvest estimates on the control lakes ranged from 1.9/ha in Lake Pierson in 2000, to 8.8/ha in Lake Zumbra in 1993, and on the experimental lakes prior to the regulation change they ranged from 2.6/ha in Lake Bavaria in 1992, to 8.2/ha in Lake Bavaria in 1993 (Table 15). On the control lakes, harvest estimates of all sizes of largemouth bass as a proportion of population estimates of largemouth bass ≥ 200 mm ranged from 0.10 on Lake Pierson in 1994, to 0.52 on Lake Zumbra in 1992; on the experimental lakes prior to the regulation change they ranged from 0.14 on Lake Bavaria in 1992, to 0.71 on Lake Bavaria in 1993[2] (Table 15).

Catch rates of largemouth bass for all anglers (targeting and non-targeting) ranged from 0.097/angler·h in Lake Ann in 1995, to 0.58/angler·h in Lake Zumbra in 2001 (Table 16). There was a significant increase in catch rates for both experimental and control lakes after the regulation, but no significant period X treatment interaction (Table 2). Catch rates of sunfish (primarily bluegill) for all anglers ranged from 0.17/angler·h in Lake Zumbra in 1992, to 4.4/angler·h in Lake Bavaria in 2000 (Table 17). There was no significant period X treatment interaction for catch rates of sunfish (Table 2).

Harvest rates of sunfish (primarily bluegill) for all anglers ranged from 0.06/angler·h in Lake Zumbra in 1992 and Lake Ann in 2000, to 1.7/angler·h in Lake Bavaria in 2000 (Table 18). Mean harvest rate of sunfish in pooled experimental lakes increased from 0.72/angler·h before the regulation (1992-1994) to 0.82/angler·h after the regulation (1996, 2000-2001), while the mean in pooled control lakes decreased from 0.38/angler·h before to 0.33/angler·h after. Mean harvest rate of sunfish in Lake Ann decreased from 0.56/angler·h before the

[2] The 1993 Lake Bavaria value is inflated because of the negatively biased population estimate.

Table 13. Estimates of angler harvest from four lakes in Carver County, Minnesota, mid-April to mid-November 1992-1996 and 2000-2001. Illegal harvest of largemouth bass occurred in Lakes Ann and Bavaria in 2000-2001, but was not quantified. The 1992-1994 data were before the experimental largemouth bass regulation, and the 1996 and 2000-2001 data were after. The 1995 values were excluded from analyses of potential regulation effects in order to have equal numbers of years before and after, and because 1995 was a transitional year.

	L. Ann[a]			L. Bavaria[a]			L. Pierson			L. Zumbra		
Species	Number	SE	Number per ha	Number	SE	Number per ha	Number	SE	Number per ha	Number	SE	Number per ha
1992												
Sunfish[b]	1,216	978	25.9	3,068	1,123	46.7	3,218	668	25.7	361	155	5.0
Largemouth bass	138	78	2.9	172	74	2.6	395	129	3.2	597	204	8.3
All species	1,756	1,042	37.3	3,669	1,145	55.9	4,225	709	33.8	1,309	275	18.1
1993												
Sunfish	6,264	1,666	133.2	11,032	2,475	168.0	2,437	673	19.5	5,255	2,380	72.7
Largemouth bass	224	71	4.8	538	265	8.2	310	97	2.5	636	175	8.8
All species	7,480	1,772	159.1	13,608	2,531	207.2	3,461	748	27.7	6,539	2,390	90.5
1994												
Sunfish	3,080	929	65.5	9,066	2,472	137.4	1,797	595	14.4	6,184	1,267	85.9
Largemouth bass	203	80	4.3	219	66	3.3	274	151	2.2	422	94	5.9
All species	3,466	946	73.7	12,403	2,914	187.9	3,818	971	30.5	7,386	1,331	102.6
1995												
Sunfish	3,604	1,406	76.7	7,362	1,775	111.5	1,644	537	13.2	5,021	1,452	69.7
Largemouth bass	58	30	1.2	31	25	0.5	298	80	2.4	517	156	7.2
All species	5,435	1,852	115.6	9,951	2,300	150.8	2,523	531	20.2	6,712	1,661	93.2
1996												
Sunfish	2,551	1,093	54.3	7,777	1,547	117.8	3,400	1,180	27.2	5,182	1,769	72.0
Largemouth bass	64	42	1.4	45	28	0.7	514	205	4.1	350	173	4.9
All species	3,249	1,170	69.1	9,437	1,743	143.0	4,579	1,030	36.6	5,997	1,963	83.3
2000												
Sunfish	440	379	9.4	13,353	3,149	202.3	2,083	826	16.7	1,163	457	16.2
Largemouth bass	--	--	--	--	--	--	238	73	1.9	217	107	3.0
All species	501	381	10.7	14,945	3,173	226.4	3,060	887	24.5	1,735	546	24.1

Table 13. Continued.

Species	L. Ann[a] Number	SE	Number per hectare	L. Bavaria[a] Number	SE	Number Per hectare	L. Pierson Number	SE	Number per hectare	L. Zumbra Number	SE	Number per hectare
2001[c]												
Sunfish	1,388	775	29.5	9,602	3,145	145.5	1,226	460	9.8	517	199	7.2
Largemouth bass	--	--	--	--	--	--	336	159	2.7	151	121	2.1
All species	1,514	777	32.2	11,637	3,247	176.3	2,147	511	17.2	1,086	324	15.1
1992-1994 averages												
Sunfish	3,520	1,191	74.9	7,722	2,023	117.3	2,484	645	19.9	3,933	1,267	54.5
Largemouth bass	188	76	4.0	310	135	4.7	326	126	2.6	552	158	7.6
All species	4,234	1,253	90.0	9,893	2,197	150.3	3,835	809	30.7	5,078	1,332	70.4
1996, 2000, 2001 averages												
Sunfish	1,460	749	31.1	10,244	2,614	155.2	2,236	822	17.9	2,287	808	31.8
Largemouth bass	--		--	--		--	363	146	2.9	240	134	3.3
All species	1,755	776	37.3	12,006	2,721	181.9	3,262	809	26.1	2,939	944	40.8

[a] Immediate release of largemouth bass required beginning in 1995.
[b] Bluegill (primarily), pumpkinseed, green sunfish, and hybrid sunfish.
[c] Adjusted for lack of October-November data.

Table 14. Observations during creel surveys of legal and illegal harvest of largemouth bass.

	L. Ann			L. Bavaria		
Year	Number of parties interviewed	Number of parties that harvested largemouth bass	Percent of parties that harvested largemouth bass	Number of parties interviewed	Number of parties that harvested largemouth bass	Percent of parties that harvested largemouth bass
			Legal harvest			
1992	113	9	8.0	159	11	6.9
1993	135	17	12.6	170	16	9.4
1994	168	24	14.3	192	19	9.9
			Illegal harvest			
1995	113	4	3.5	130	2	1.5
1996	135	4	3.0	162	4	2.5
			Pooled observations			
Legal	416	50	12.0	521	46	8.8
Illegal	248	8	3.2	292	6	2.1

Table 15. April - November harvest of all sizes of largemouth bass as a proportion of the April-May population estimate of largemouth bass ≥ 200 mm in four lakes in Carver County, Minnesota. The 1993 L. Bavaria value may be inflated by a negatively biased population estimate.

Year	L. Ann	L. Bavaria	L. Pierson	L. Zumbra
1992	0.21	0.14	0.11	0.52
1993	0.17	0.71	0.21	0.25
1994	0.26	0.33	0.10	0.16
1995			0.11	0.32
1996			0.12	0.34
2000			0.21	0.18
2001			0.34	0.11
			1992-1994	
Mean	0.21	0.39	0.14	0.31
SD	0.05	0.29	0.06	0.19
			1995-1996, 2000-2001	
Mean			0.20	0.24
SD			0.11	0.11

Table 16. Catch rates (number/angler•h) of largemouth bass by all anglers (targeting and non-targeting) in four lakes in Carver County, Minnesota.

	Year						
	1992	1993	1994	1995	1996	2000	2001
L. Ann	0.153	0.188	0.162	0.097	0.228	0.333	0.339
L. Bavaria	0.110	0.280	0.128	0.343	0.348	0.250	0.214
L. Pierson	0.116	0.224	0.260	0.275	0.374	0.217	0.163
L. Zumbra	0.268	0.374	0.319	0.281	0.223	0.523	0.578

Table 17. Catch rates (number/angler•h) of sunfish (primarily bluegill) by all anglers (targeting and non-targeting) in four lakes in Carver County, Minnesota.

	Year						
	1992	1993	1994	1995	1996	2000	2001
L. Ann	0.71	1.76	2.03	1.82	1.21	0.77	0.94
L. Bavaria	0.68	3.32	2.44	2.70	2.54	4.41	3.64
L. Pierson	0.95	1.84	2.19	1.28	1.24	0.44	0.44
L. Zumbra	0.17	1.44	2.14	1.86	1.88	1.61	1.45

Table 18. Harvest rates (number/angler•h) of sunfish (primarily bluegill) by all anglers (targeting and non-targeting) in four lakes in Carver County, Minnesota.

	Year						
	1992	1993	1994	1995	1996	2000	2001
L. Ann	0.29	0.87	0.52	0.68	0.40	0.06	0.22
L. Bavaria	0.39	1.27	0.98	1.15	1.04	1.71	1.46
L. Pierson	0.32	0.39	0.24	0.24	0.43	0.21	0.15
L. Zumbra	0.06	0.66	0.61	0.59	0.75	0.31	0.11

regulation to 0.23/angler·h after the regulation, but in Lake Bavaria increased from 0.88/angler·h before to 1.4/angler·h after. The overall period X treatment interaction was not significant (Table 2).

Mean total lengths of harvested bluegill ranged from 132 mm in Lake Ann in 2001 to 182 mm in Lake Zumbra in 1995, and maximum lengths ranged from 177 mm in Lake Pierson in 1996 to 234 mm in Lake Pierson in 2000 (Table 19). The mean for the experimental lakes before the regulation change (1992-1994) was 170 mm, and 167 mm after the regulation change (1996, 2000-2001). The mean for the control lakes was 167 mm before, and 169 mm after. There was no significant period X treatment interaction (Table 2). The average maximum for the experimental lakes before the regulation change (1992-1994) was 196 mm, and 203 mm after the regulation change (1996, 2000-2001). The average maximum for the control lakes was 201 mm before, and 206 mm after. Again, there was no significant period X treatment interaction (Table 2).

Table 19. Total length (mm) summaries of samples of bluegill harvested by anglers from four lakes in Carver County, Minnesota.

	Year						
	1992	1993	1994	1995	1996	2000	2001
				L. Ann			
N	43	126	173	180	168	15	22
Minimum	142	111	124	107	95	140	94
Maximum	184	183	198	192	201	193	198
Mean	165	166	164	162	173	166	132
SD	12	12	13	17	20	20	23
				L. Bavaria			
N	153	350	201	196	625	301	228
Minimum	141	130	123	145	136	122	140
Maximum	192	207	211	213	208	203	213
Mean	166	181	176	178	181	172	177
SD	10	11	18	14	11	14	11
				L. Pierson			
N	315	42	56	132	176	88	23
Minimum	99	131	139	146	138	130	137
Maximum	222	194	179	201	177	234	191
Mean	166	161	158	164	162	174	170
SD	15	14	9	11	9	13	14
				L. Zumbra			
N	54	95	314	151	261	66	35
Minimum	133	155	153	155	130	133	157
Maximum	180	211	219	221	210	219	203
Mean	163	175	179	182	164	169	177
SD	10	13	12	12	11	15	11

Discussion and Management Implications

We found only a weak negative correlation between largemouth bass density and bluegill recruitment. Consistent with the lack of a strong effect of largemouth bass on bluegill recruitment, there was no evidence the experimental regulation prohibiting largemouth bass harvest had any beneficial effect on bluegill abundance, growth, and size structure, or the quality of the bluegill fisheries. There are at least three potential explanations for the apparent lack of a strong biological interaction between largemouth bass and bluegill. First, largemouth bass densities in this study were relatively low compared to the range of published values (Hall 1986; Gabelhouse 1987; Coble 1992; McInerny and Degan 1993; Hill and Willis 1994; McKibbin 2002), so it may be that densities were simply too low for largemouth bass to have a strong influence on bluegill recruitment. Also, the presence of diverse fish communities (Table 4) containing other potential bluegill predators (e. g., northern pike, bowfin *Amia calva*, and yellow perch) and largemouth bass prey (e. g., cyprinids and yellow perch *Perca flavescens*) may have weakened the predator-prey linkage between largemouth bass and bluegill relative to lakes with simpler fish communities. Predation by largemouth bass may not sufficiently control bluegill or crappie recruitment if preferred prey of other species are abundant in the community (Timmons et al. 1980; Carline et al. 1984; Reed and Parsons 1996). Although Paukert et al. (2002) did find a positive correlation between largemouth bass density and bluegill quality in Nebraska sandhill lakes that contained northern pike, yellow perch, and other potential predator or prey species, improvement of bluegill size structure through manipulation of largemouth bass populations is probably most likely to succeed in lakes with simple fish communities and the capacity to support dense largemouth bass populations. Most naturally formed lakes in Minnesota do not fit this description. Finally, the northern latitude of our study lakes relative to most of those in the literature on largemouth bass and bluegill interactions may have weakened the effect of largemouth bass on bluegill. Modde and Scalet (1985), using growth data from southern (Oklahoma) and northern (Montana) populations, simulated bluegill and largemouth bass populations and found age ≥ 1 bluegill two times more vulnerable to largemouth bass predation in the southern population because there was a higher proportion of larger largemouth bass as a result of faster largemouth bass growth rates. Therefore, the southern largemouth bass population was capable of preying on larger bluegill. However, we are skeptical about the relevance of Modde and Scalet (1985) to this study. In our study lakes, bluegill growth was less than or equal to that in the Montana population; largemouth bass growth rates were intermediate between Oklahoma and Montana; and largemouth bass size structure was much closer to the Oklahoma population than the Montana population. Therefore, age ≥ 1 bluegill in the Minnesota populations should have been much more vulnerable than in the simulated Montana population. In any case, if bluegill year class strengths are determined during the first year of life, then any latitudinal growth effects on largemouth bass size structure are relatively unimportant because even very small largemouth bass are capable of preying on age-0 bluegill (Garvey and Stein 1998).

In addition to the fact that largemouth bass did not have a strong effect on bluegill recruitment in this study, recruitment probably was not the primary variable limiting bluegill quality. Bluegill growth curves and size structures did not indicate the populations were truly “stunted” due to excessive population densities. Growth and mortality rates up to about age 6 or 7 allowed moderate to high percentages of the populations to exceed 150 mm, and thus PSDs were generally within or even above recommended ranges (Table 8; Figure 9; Appendix 2). However, few, if any, individuals exceeded 200 mm (Table 8; Appendix 2). This could be because exploitation was high enough to suppress abundance of preferred-size fish directly by cropping off the largest, fastest-growing individuals (Coble 1988; Jennings et al. 1997), or indirectly by socially inducing reduction in the average age and size at maturity of males through selective harvest of large, dominant parentals (Beard et al. 1997; Drake et al. 1997; Ehlinger 1997; Jennings et al. 1997; Beard and Essington 2000). Rather than attempting to reduce bluegill density by manipulating largemouth bass regulations, a more promising management option for improving bluegill size structure in typical heavily exploited Minnesota lakes may be to reduce bluegill harvest (Jacobson, in review). This approach might be effective on a lake such as Bavaria, which had moderate to high PSD, a relatively high harvest rate, and growth curves that indicated substantial numbers of fish might exceed 200 mm if mortality were reduced or male age at maturity were increased.

We found no correlation between bluegill abundance (as indexed by trap net catch) and bluegill PSD, and no consistent relationship between bluegill PSD and largemouth bass PSD or RSD-P. If the trap net catch was representative of bluegill abundance, then the absence of a significant correlation between bluegill PSD and trap net catch indicates bluegill PSD was not density-dependent. Changes in bluegill PSD over the years probably reflected wide fluctuations in recruitment, but there was little apparent correlation between changes in bluegill recruitment and changes in largemouth bass populations. These results do not lend any support to the assumption that there is a cause-and-effect relationship between largemouth bass size structure and bluegill size structure in Minnesota Class 24 lakes. Therefore, the concept of "balance" between largemouth bass and bluegill size structure (Anderson 1976, 1980) may not be applicable to this lake type. In addition, correct interpretation of size structure is difficult without additional data (Carline et al. 1984). Therefore, Minnesota fisheries managers should be cautious about using largemouth bass and bluegill PSD and RSD as anything more than standard ways to describe length frequency distributions.

The experimental regulation prohibiting harvest of largemouth bass appeared to have a positive effect on density of largemouth bass ≥ 200 mm by contributing to an increase in the case of Lake Bavaria, and slowing a decline in the case of Lake Ann. However, because the responses differed and the number of lakes was small, the overall effect was not significant, even though both lakes individually exhibited positive effects of the experimental regulation. The negatively biased 1993 population density estimate for Lake Bavaria accentuated the increase attributed to the experimental regulation, but the period X treatment interaction still would have been significant if the population density estimate had been increased by much as 500% (Table 20). Since a 500% increase would far exceed any other population estimate, it is unlikely the bias was large enough to result in a false positive regulation effect.

Largemouth bass growth was not significantly affected by the regulation change, although there was some evidence of a density-dependent decline in Lake Bavaria. Angler catch rates of largemouth bass increased similarly in experimental regulation lakes and control lakes after the regulation change. Both experimental regulation lakes and control lakes had moderate to high quality largemouth bass populations before and after implementation of the experimental regulation based on PSD, RSD-P, and RSD-M (Gabelhouse 1984). Gabelhouse's (1984) recommended minimum trophy length of 630 mm is probably unrealistically high for Minnesota largemouth bass populations, because the Minnesota state record largemouth bass was only 597 mm. Consistent with the findings of McInerny and Cross (1996), size selectivity of daytime April-May electrofishing for largemouth bass ≥ 200 mm was minimal, and did not substantially affect conclusions. Quality of largemouth bass populations improved in the experimental regulation lakes relative to the control lakes, but the difference was not large enough to be statistically significant given the small sample size and highly variable data. Additional research is needed on a larger sample of lakes to conclusively evaluate potential benefits of no-harvest regulations to the size structure of Minnesota largemouth bass populations.

Exploitation rates of largemouth bass appeared to be high enough to influence population density and size structure. However, evaluation of the true effect of harvest on the largemouth bass populations was confounded by illegal harvest of largemouth bass in the experimental regulation lakes and voluntary release of largemouth bass by a substantial majority of angling parties on the control lakes, which in combination reduced the contrast between the experimental lakes and control lakes. Noncompliance by even a small percentage of anglers on the experi- mental regulation lakes would have been exacerbated by the fact that effort tended to be higher per hectare on the experimental lakes than on the control lakes. Depending upon severity, illegal harvest can increase

Table 20. Hypothetical revised results of a univariate repeated measures ANOVA of population densities of largemouth bass ≥ 200 mm in Lake Bavaria and two pooled control lakes before (1992-1995) and after (1998-2001) implementation of a no-harvest regulation on largemouth bass in Lake Bavaria. The actual negatively biased estimate of 1993 Lake Bavaria population density was adjusted upward by 500% (from 11.5/ha to 69.3/ha) in order to determine how much higher an unbiased estimate could be and still result in a significant period X treatment interaction.

Source	SS	df	MS	F	P
Period	418.901	1	418.901	2068.646	**0.014**
Period X treatment	46.021	1	46.021	227.263	**0.042**
Error	0.202	1	0.202		

the time frame for fulfillment of potential benefits -- particularly critical in our circumstance where response from bluegill populations was the ultimate goal -- or it can cause serious reduction in benefits (Gigliotti and Taylor 1990). Others have also expressed concern about noncompliance with special regulations (Glass and Maughan 1984; Paragamian 1984; Pierce and Tomcko 1997). The creel surveys probably underestimated the magnitude of the illegal harvest because the conspicuous presence of the creel survey clerk undoubtedly deterred intentional violators. Most angling parties who illegally possessed largemouth bass in 2000 and 2001 appeared to be unaware of the experimental regulation despite listing in the state fishing regulations guidebook and posting of signs at public access points.

Herbicide applications to Lakes Bavaria and Zumbra in an attempt to eradicate Eurasian watermilfoil may have confounded the results of this experiment. A whole-lake application of the herbicide fluridone to Lake Zumbra in May 1994 substantially reduced abundance and diversity of macrophytes in 1994 and 1995, accelerating growth rates of both bluegill and largemouth bass by increasing predation of largemouth bass on small bluegill (Pothoven et al. 1999). The reduction in macrophytes also may have influenced angler effort, catch, and harvest (Unmuth et al. 2001), as well as catchability of bluegill in trap nets. Although 2,4-D applications to the entire littoral zone of Lake Bavaria in 1992 and 1993 were much less destructive, they did cause unaccountable change in plant communities that may have influenced results. In addition, the fact that Eurasian watermilfoil became established in Lake Ann in the middle of the study period (circa 1995) is problematic because its potential effects began at about the same time as the experimental regulation.

The small sample of lakes in this experiment, coupled with the high degree of variability in the data, made it unlikely that we would detect regulation effects unless they were strong. Therefore, in some respects this study was inconclusive, particularly with regard to potential benefits of the no-harvest regulation to quality of the largemouth bass populations. The variability encountered in this study is typical for fisheries field data, so future attempts to evaluate experimental regulations should not be initiated with such a small sample of lakes. Substantial increases in statistical power could have been achieved with a modest increase in sample size. For example, the addition of just one more experimental regulation lake and one more control lake to this experiment would have doubled the error degrees of freedom in the repeated measures ANOVAs for pooled experimental lakes and pooled control lakes from 2 to 4, and for individual treatment lakes and pooled control lakes from 1 to 2. An additional benefit of increasing the sample size would have been to decrease the potential influence of isolated uncontrolled events such as herbicide treatments.

Fisheries managers have often attempted to evaluate effects of a regulation change with a before-after experimental design on an individual treatment lake. This study illustrates the critical importance of control lakes to the evaluation of regulation changes. Trends on our experimental regulation lakes could have resulted in wrong conclusions if we had not included control lakes in the experimental design. For example, angler catch rates of largemouth bass increased on the experimental regulation lakes after the experimental regulations were implemented. If we had been optimistic about the effectiveness of the experimental regulation we would have been tempted to conclude the improvement was due to the regulation, when in fact a similar improvement occurred on the control lakes with standard regulations. On the other hand, if we had evaluated Lake Ann by itself or in comparison to the other experimental regulation lake, we likely would have interpreted the slight decrease in density of largemouth bass after the experimental regulation was implemented as a failure of the regulation, when in actuality there was a positive effect because the decline was significantly less than in the control lakes. The control lakes could be outside the local fisheries management area as long as they are reasonably similar to the experimental regulation lakes, and could also be used in evaluations of other comparable experimental regulation lakes. This approach would minimize the effort required for local fisheries management staff to evaluate the experimental regulation.

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Appendix 1. Total numbers of largemouth bass examined for marks (C) after the initial marking day, and total numbers of recaptured fish (R), in four lakes in Carver County, Minnesota during modified Schnabel population estimates.

	Length class (mm)								
	≥ 200			≥ 300			≥ 380		
Year	C	R	R/C	C	R	R/C	C	R	R/C
				L. Ann					
1992	102	7	0.069	74	7	0.095	62	4	0.065
1993	128	5	0.039	72	3	0.042	49	3	0.061
1994	127	9	0.071	63	5	0.079	39	3	0.077
1995	133	14	0.105	92	8	0.087	65	8	0.123
1996	177	30	0.169	146	27	0.185	64	12	0.188
1997	130	18	0.138	112	17	0.152	54	10	0.185
1998	107	14	0.131	100	13	0.130	62	8	0.129
1999	230	34	0.148	173	28	0.162	154	25	0.162
2000	233	47	0.202	204	43	0.211	168	39	0.232
2001	136	17	0.125	76	10	0.132	50	8	0.160
Mean	150	20	0.120	111	16	0.127	77	12	0.138
				L. Bavaria					
1992	170	9	0.053	127	8	0.063	41	5	0.122
1993	51	2	0.039	18	1	0.056	4	1	0.250
1994	141	15	0.106	69	6	0.087	38	2	0.053
1995	170	20	0.118	98	13	0.133	26	3	0.115
1996	213	32	0.150	138	25	0.181	44	8	0.182
1997	126	10	0.079	105	10	0.095	43	1	0.023
1998	160	20	0.125	114	15	0.132	75	9	0.120
1999	290	28	0.097	216	25	0.116	157	22	0.140
2000	431	60	0.139	348	54	0.155	242	38	0.157
2001	211	29	0.137	114	10	0.088	68	8	0.118
Mean	196	23	0.104	135	17	0.110	74	10	0.128
				L. Pierson					
1992	311	9	0.029	172	8	0.047	82	4	0.049
1993	146	6	0.041	99	5	0.051	55	2	0.036
1994	284	12	0.042	158	7	0.044	93	2	0.022
1995	308	15	0.049	160	9	0.056	97	7	0.072
1996	300	10	0.033	239	10	0.042	113	6	0.053
1997	250	12	0.048	173	8	0.046	94	2	0.021
1998	184	15	0.082	139	11	0.079	62	4	0.065
1999	335	34	0.101	258	24	0.093	109	11	0.101
2000	261	35	0.134	187	30	0.160	102	15	0.147
2001	194	27	0.139	151	24	0.159	63	13	0.206
Mean	257	18	0.070	174	14	0.078	87	7	0.077
				L. Zumbra					
1992	182	13	0.071	102	12	0.118	50	6	0.120
1993	219	7	0.032	145	6	0.041	45	3	0.067
1994	369	30	0.081	202	15	0.074	93	12	0.129
1995	311	30	0.096	169	17	0.101	64	3	0.047
1996	253	40	0.158	220	36	0.164	86	13	0.151
1997	172	15	0.087	123	9	0.073	71	6	0.085
1998	136	12	0.088	111	10	0.090	56	6	0.107
1999	312	51	0.163	210	39	0.186	111	19	0.171
2000	308	45	0.146	192	33	0.172	115	18	0.157
2001	165	24	0.145	101	16	0.158	59	9	0.153
Mean	243	27	0.107	158	19	0.118	75	10	0.119

Appendix 2. Bluegill trap net catch at age for four lakes in Carver County, Minnesota, estimated from age-length keys.

	Year									
Age	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
					L. Ann					
1	49		1	20	79	24	242	283	31	142
2	20	15			21	17	58	138	122	54
3	89	21	27	1	1	41	26	58	73	100
4	113	88	49	45	4	6	31	18	25	28
5	25	111	74	37	14	21	1	1	2	14
6	21	185	34	32	9	53	4	1	1	1
7		13		8	1	14	9	2		1
8							4			
9							1			
10										
					L. Bavaria					
1	55	4	5	181	66	14	19	233	89	22
2	18	19	20	26	73	12	57	27	54	28
3	40	2	64	25	7	73	47	145	40	129
4	64	21	10	101	27	23	76	92	90	25
5	46	22	40	23	83	89	8	69	146	26
6	86	55	47	28	50	251	1	4	21	23
7	3	19	9	5	25	48	1			
8					4	20				
9						1		2		
10										
					L. Pierson					
1				6	4		21	36		8
2	4	2		1	25	2	2	28	3	43
3	49	20	13			17	11	5	11	93
4	66	240	99	34		21	39	18	25	47
5	74	71	146	315	97	11	6	21	31	6
6	33	99	5	90	157	112	3	11	29	19
7	24	25		1	78	191	27	10	9	1
8	4	6				107	28	9	18	
9								4	5	
10								2	7	6
						L. Zumbra				
1	2		8	28	43		56	93	55	5
2	21	3		12	98	40	2	93	89	84
3	3	45	13	1	48	73	47	29	55	159
4	7	63	57	65	5	3	57	49	49	28
5	26	69	38	234	58	3	8	39	31	18
6	18	48	23	64	169	79	4	6	20	1
7	10	42	21	13	7	32	1	1	3	7
8	2	14	2	8	2				1	
9		4	2	2						
10				2						